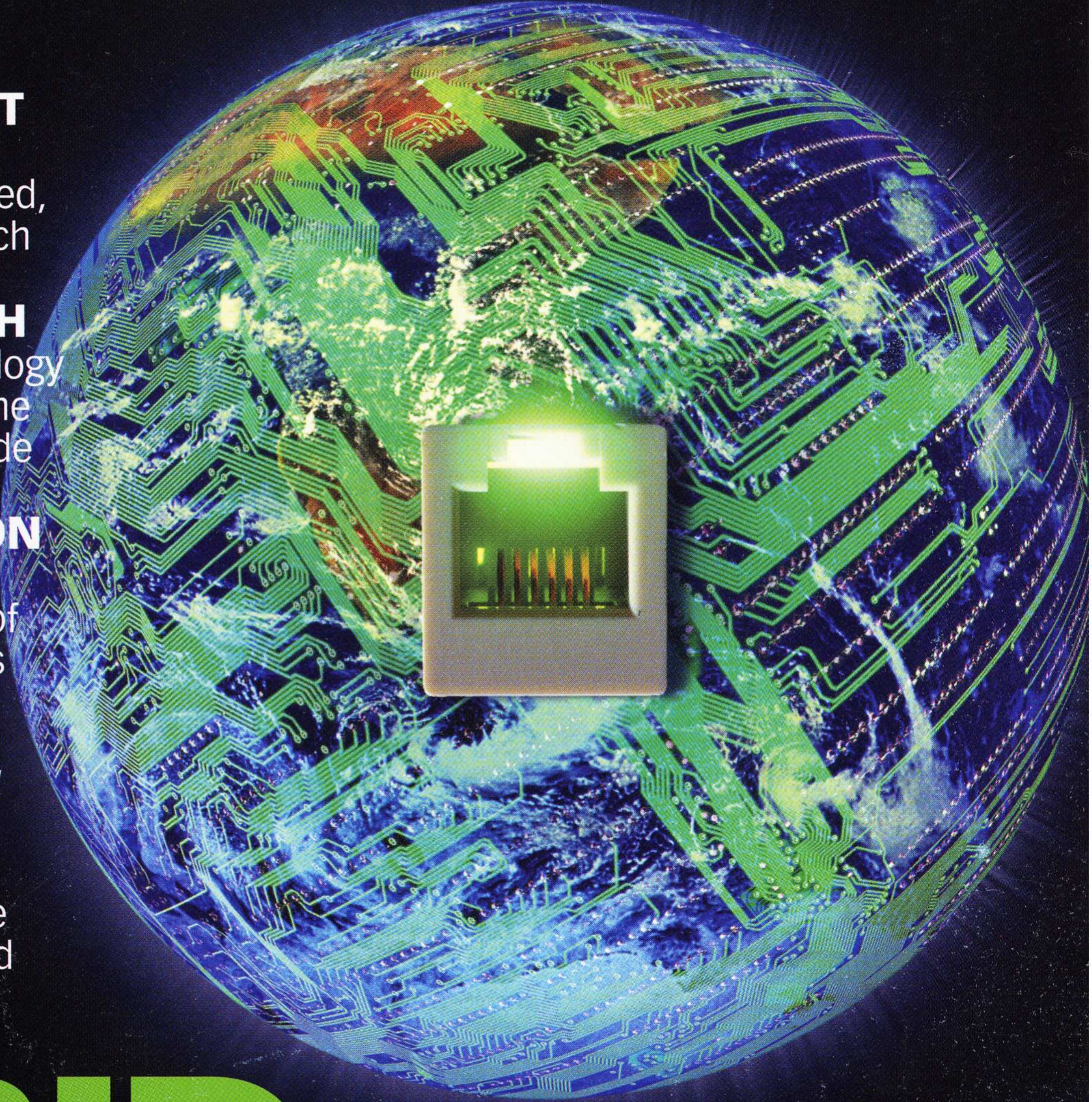
MIT'S MAGAZINE OF INNOVATION

TECHNOLOGY REVIEW

MAY 2002

WWW.TECHNOLOGYREVIEW.COM



THE *TR* PATENT SCORECARD
150 companies rated, + 5 Patents to Watch

NANOBIOTECH
When nanotechnology meets medicine, the diagnosis gets made

THE INVENTION FACTORY
An exclusive tour of Nathan Myhrvold's new brainchild

MAKING NEW VACCINES
Does a national shortage mean the government should get involved?

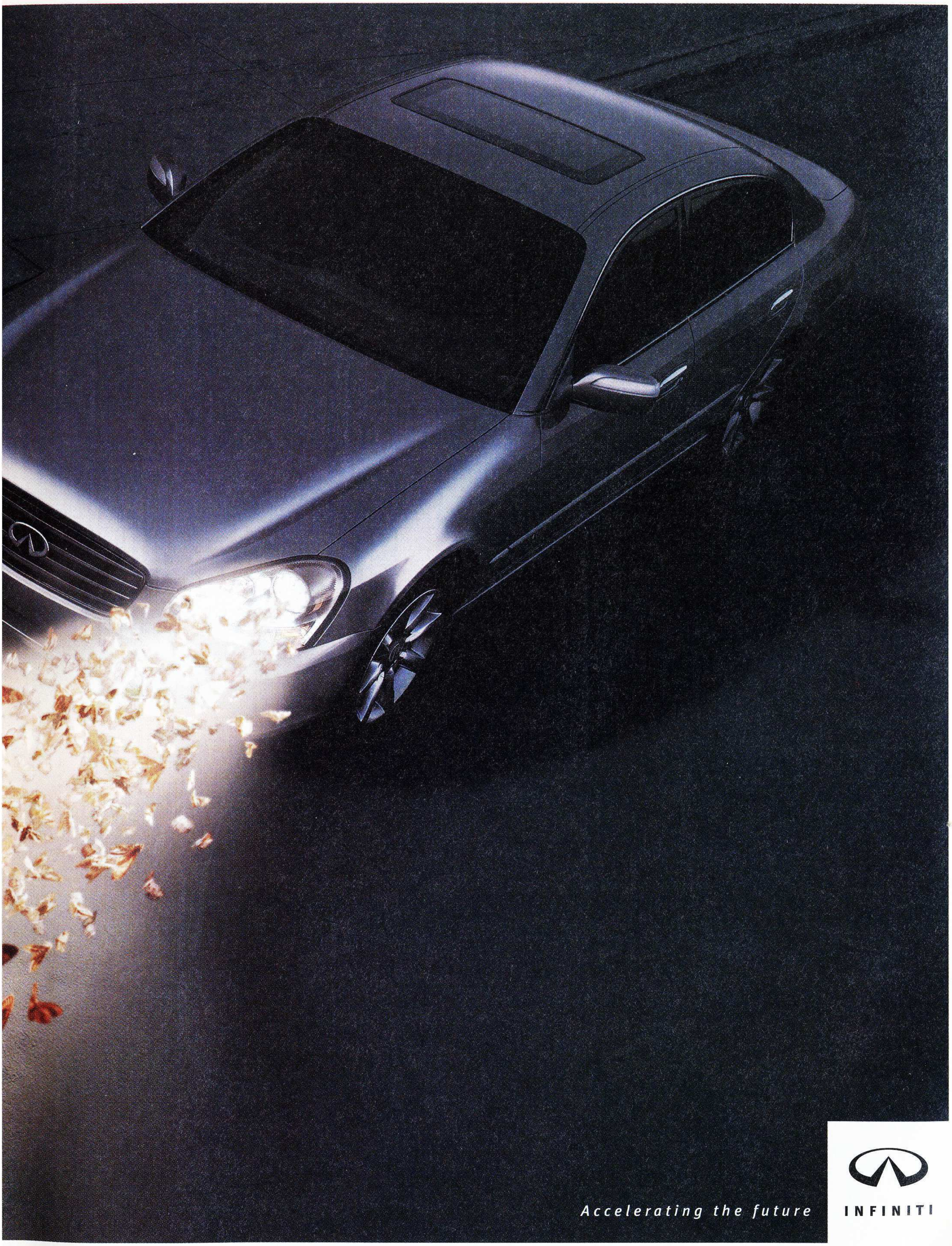
GRID COMPUTING
Envision a global system that puts computer power on tap just like water

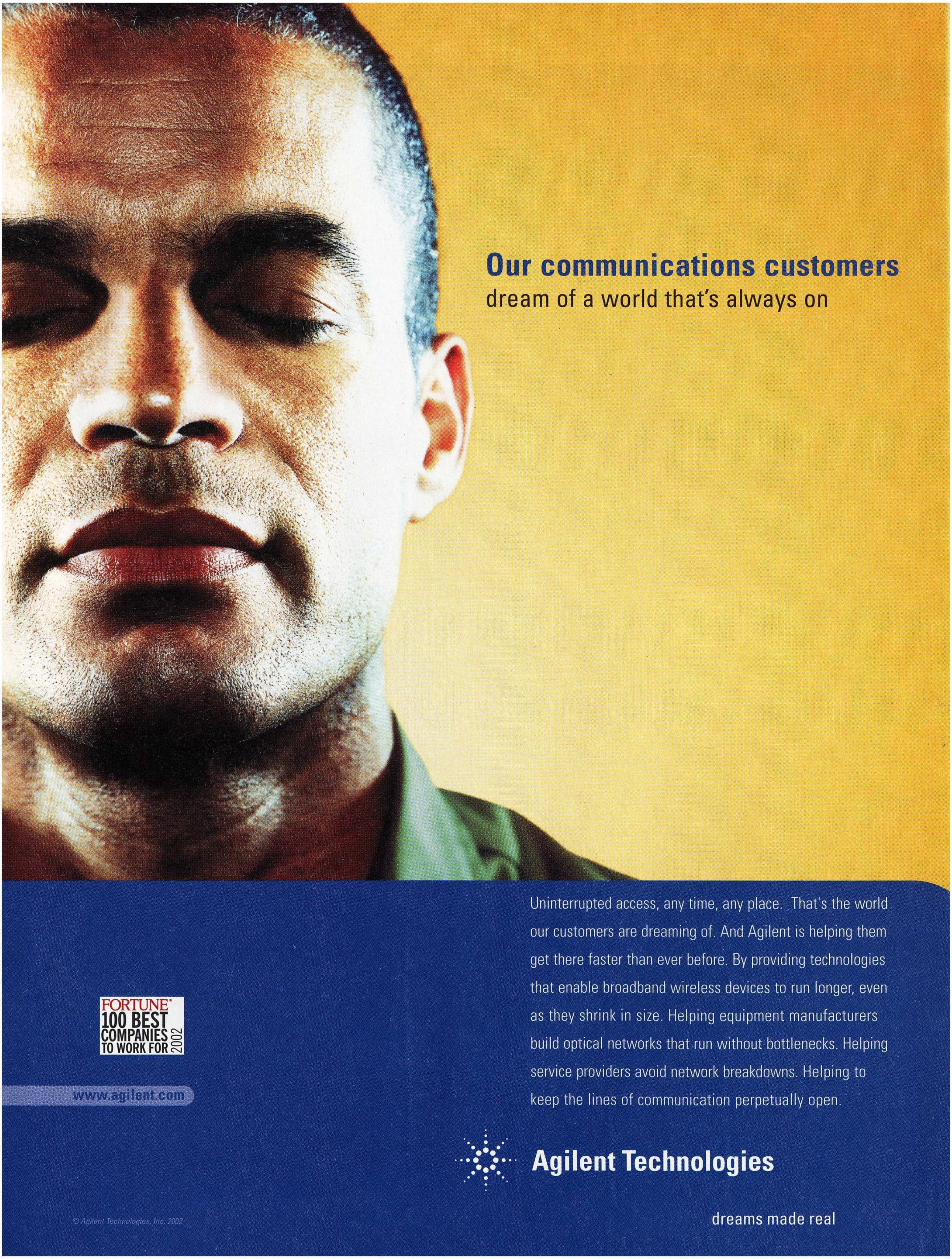
USA $4.99 • CANADA $6.99

Oracle wanted to switch to on-demand printing
perfect digital solution and saved them

Learn more: www.xerox.com/learn **For a sales rep: 1-800-ASK-XEROX ext. LEARN**


TheNewQ.com/WorldsMostPowerfulHeadlights
Seven individual, optically tuned lenses focus the Q45's high-intensity xenon beams more powerfully than any other headlight in the world. See. And be seen.

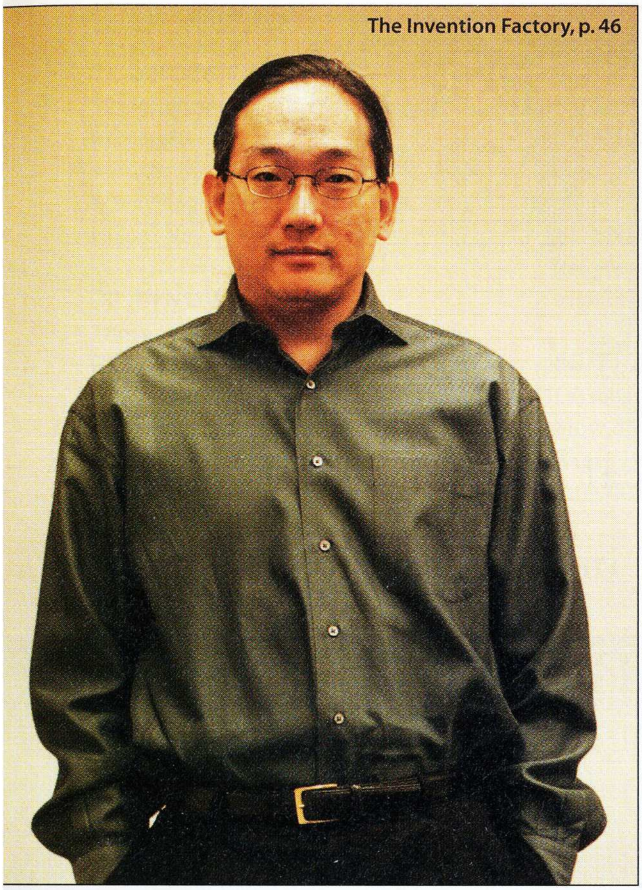

Accelerating the future
INFINITI


Our communications customers
dream of a world that's always on
Uninterrupted access, any time, any place. That's the world our customers are dreaming of. And Agilent is helping them get there faster than ever before. By providing technologies that enable broadband wireless devices to run longer, even as they shrink in size. Helping equipment manufacturers build optical networks that run without bottlenecks. Helping service providers avoid network breakdowns. Helping to keep the lines of communication perpetually open.
FORTUNE 100 BEST COMPANIES TO WORK FOR 2002
www.agilent.com
Agilent Technologies
dreams made real
© Agilent Technologies, Inc. 2002

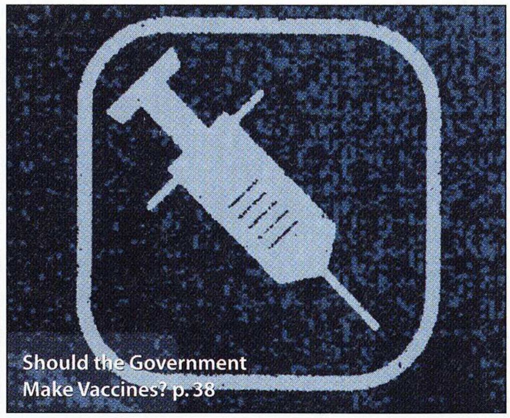
CONTENTS

FEATURES

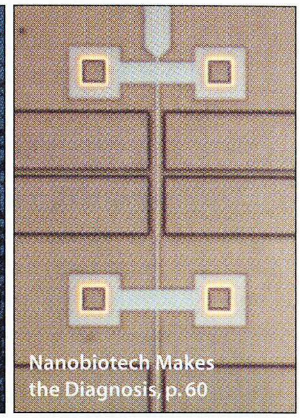
TECHNOLOGY REVIEW VOLUME 105, NUMBER 4



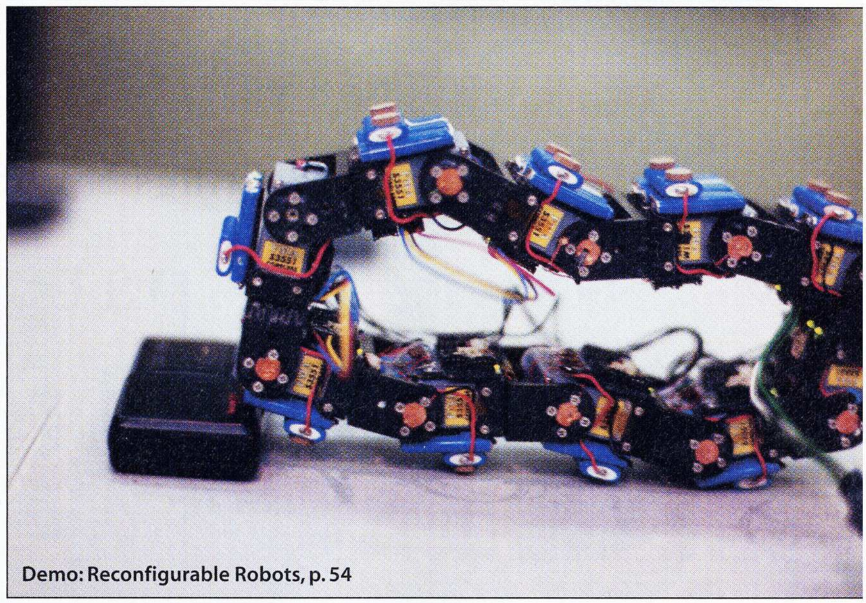
The Invention Factory, p. 46



Should the Government Make Vaccines? p. 38



Nanobiotech Makes the Diagnosis, p. 60



Demo: Reconfigurable Robots, p. 54

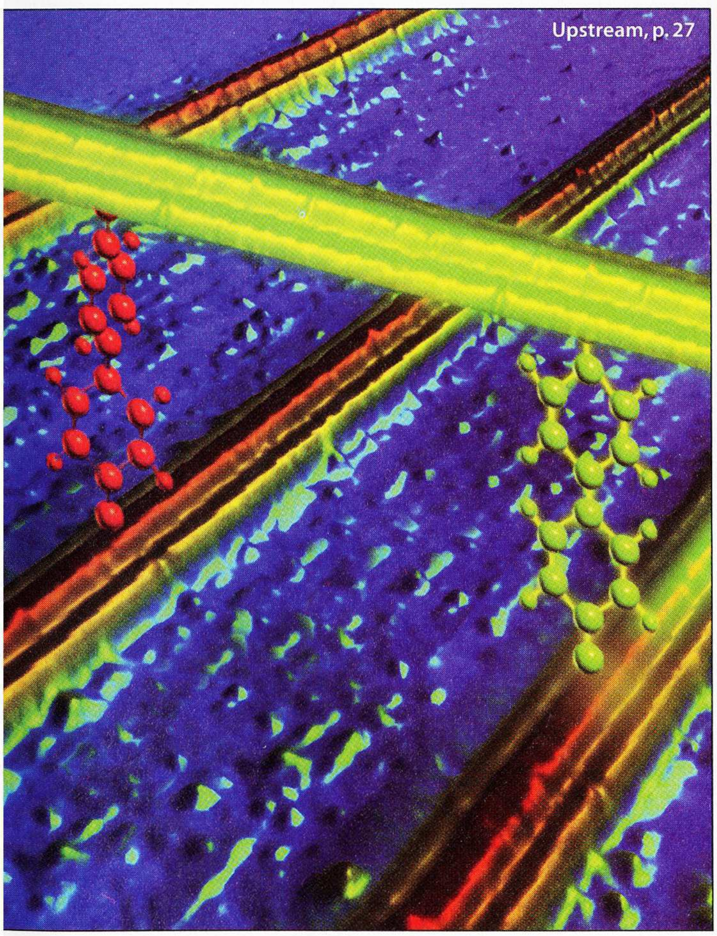
May 2002

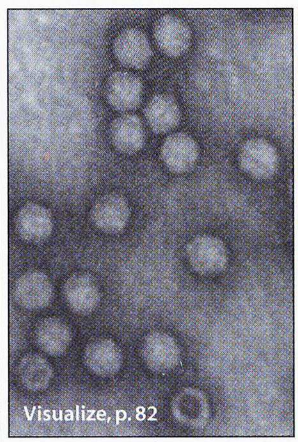
COVER ILLUSTRATION: JAMES PORTO

CONTENTS

DEPARTMENTS

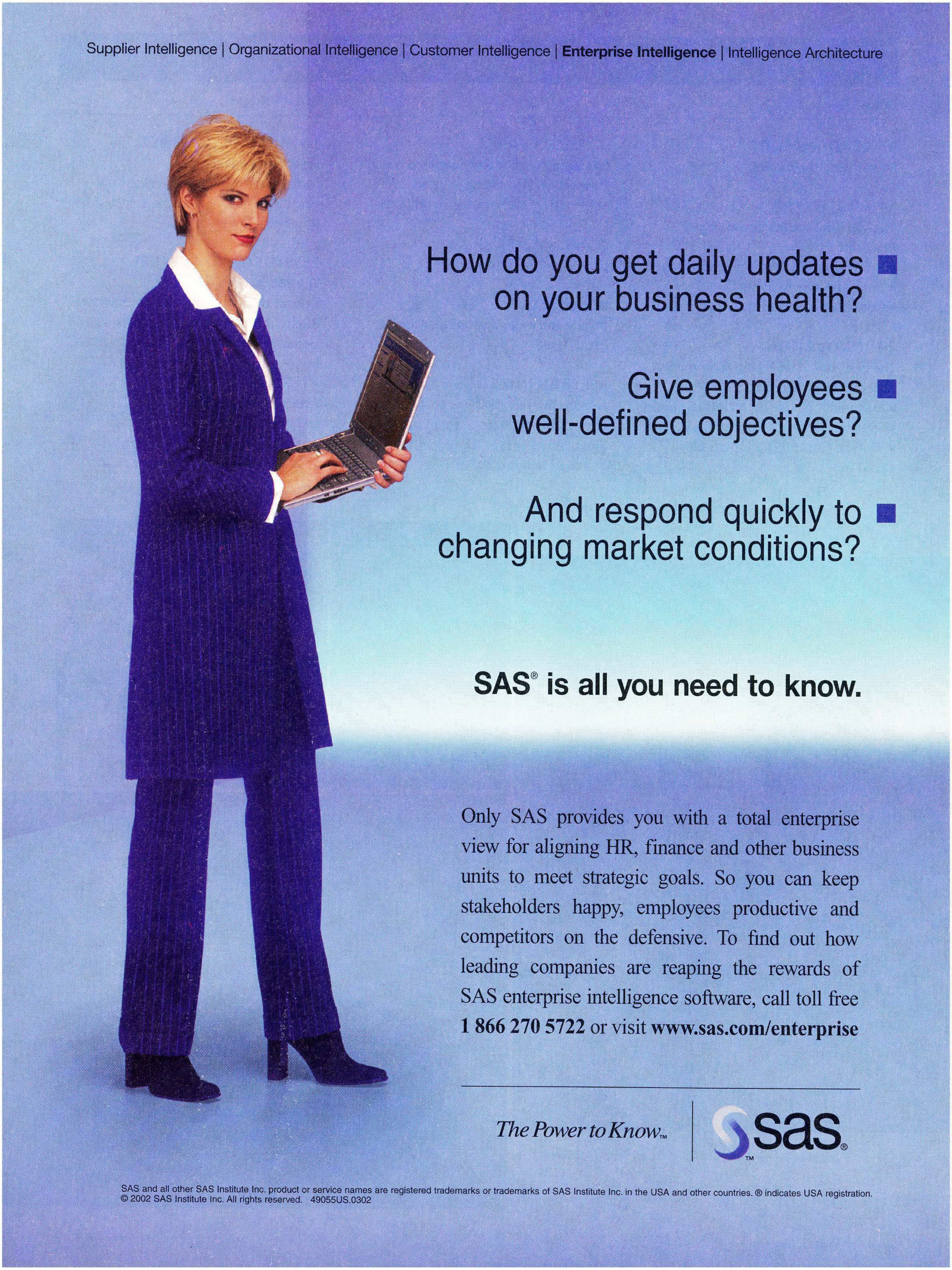
COLUMNS


Upstream, p. 27


Visualize, p. 82


Innovation, p. 20


Trailing Edge, p. 88


Supplier Intelligence | Organizational Intelligence | Customer Intelligence | **Enterprise Intelligence** | Intelligence Architecture
How do you get daily updates on your business health?
Give employees well-defined objectives?
And respond quickly to changing market conditions?
SAS® is all you need to know.
Only SAS provides you with a total enterprise view for aligning HR, finance and other business units to meet strategic goals. So you can keep stakeholders happy, employees productive and competitors on the defensive. To find out how leading companies are reaping the rewards of SAS enterprise intelligence software, call toll free **1 866 270 5722** or visit **www.sas.com/enterprise**
The Power to Know™
sas®
SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc. in the USA and other countries. ® indicates USA registration.
© 2002 SAS Institute Inc. All rights reserved. 49055US.0302

HOW THE TECHNOLOGY WORKS

How quickly time moves. The issue you're holding marks four years since we relaunched *Technology Review*, which had previously focused mainly on technology policy, as MIT's Magazine of Innovation. In those four years, our mantra has been continuous improvement. Continuous improvement is an idea that's often applied to manufacturing, but there's no reason it shouldn't be applied to making a magazine as well as to making truck bodies. And at *Technology Review*, it has been: we're looking constantly for the weak spots in what we offer you and replacing them with elements we think will work better.

The first and biggest change, of course, was the relaunch. The May/June issue of 1998 represented an entirely different magazine than had the immediately preceding issue. The purview of the new publication was innovation: the strategies by which organizations attempt to remain ahead of the curve and the most important technologies currently emerging from research laboratories.

Surveys of our readers after the relaunch made several points clear. First, the people reading the new *Technology Review* were far more interested in the new technologies than they were in the managerial strategies aimed at bringing forth those new technologies. Editorial research is less efficient at identifying reasons for preferences than it is at fingering the preferences themselves, but my guess is that information about the process of innovation is available elsewhere; reliable information about the technologies isn't.

The second thing we learned was that our readers wanted to know about technologies that are going to appear on the market in the relatively near future—over the next three years or so. Again, the underlying motivation wasn't clear from the research, but my guess is that in a rapidly changing technological environment, anything more than three years away seems too distant and too speculative to have practical significance.

Based on these findings, we modified the focus of *Technology Review* yet again. In January 2001, when we began publishing monthly rather than every other month, our byword was no longer innovation in general; it was "emerging technologies and their impact." And that has remained our focus.

Our continued editorial surveying over the last year indicates that this approach is resonating with you. But that doesn't mean we've stopped finding ways to improve. In particular, we've been looking closely at the kinds of information you want in each *Technology Review* article. In our surveys, we ask a cross section of readers to choose which components of our feature stories are most important to them. Among the possible choices: how the technology works, when it will reach the market, who the people behind it are, and the impact the new technology will have on readers and their organizations.

In every survey we've ever done, one answer—*how the technology works*—has overwhelmed the others. Since research, as I've mentioned, provides the "what" but not the "why," I've conjured for myself a vision of the *Technology Review* reader. And the conclusion I've come to is that you, as a group, are people who want the clearest, most trustworthy description of emerging technologies that you can get; after that, you'll draw your own conclusions.

That message has come through clearly, and in this issue you will see changes reflecting the fact that we hear you. Our Web site has been developed to a higher level than it had previously reached, and we're moving two of our regular offerings there, because we think they'll work better online. As of this issue, our letters column ("Feedback") will move to the Web, where there will be opportunity to present more letters and engage readers in additional give and take. Henry Jenkins's column, "Digital Renaissance," will move to our Web site, where it has consistently been a favorite.

In this issue we once again offer our readers a suite of changes aimed at improving our magazine. Among others: a new department that gives you a front-row seat at a demo of new technology.

In keeping with the hypothesis that our readers prefer facts to opinions, we're discontinuing the essay department, recently called "Insight." Because you've told us you're more interested in the technology than you are in the people behind it, our interview feature, "Q&A," has been transformed into a new department called "Demo." In "Demo" we'll still be bringing you face to face with today's most vital innovators. But instead of simply asking them questions and hearing their answers, we're going to ask them to demonstrate the most exciting prototype technology they're working on. We'll send a photographer along with our reporter, so that you'll be able to witness the demo yourself. In the first incarnation of this new department, Mark Yim of the Palo Alto Research Center displays robots that assemble themselves into new configurations in response to specific conditions.

This round of changes may not be quite as dramatic as its predecessors. Then again, continuous improvement doesn't always mean that it's necessary to tear your work apart and reinvent it. But it does mean we need to keep probing for weak spots and fixing them. That's what we've tried to do in this issue, and that is what we will continue to do as we move the new *Technology Review* forward. TR

▸ SUBSCRIBER SERVICES

BACK ISSUES
To order a back issue, please visit our Web site at **www.technologyreview.com/custserv/backissue.** Or send a check or money order for $6.50 to *Technology Review* Back Issues Dept., PO Box 420235, Palm Coast, FL 32142-0235.

ARTICLE REPRINTS (100 OR MORE)
Contact Reprint Management Services at 717-399-1900, sales@rmsreprints.com or **www.rmsreprints.com.**

PERMISSION TO PHOTOCOPY
Contact Copyright Clearance Center at 978-750-8400, fax at 978-750-4470, or online at **www.copyright.com.**

PERMISSION TO REPUBLISH
To use an article (text only) or other contents of *Technology Review* in a newsletter, newspaper, brochure, pamphlet, journal, magazine, text or trade book, dissertation, presentation, advertisement, CD-ROM or Web site, please contact Copyright Clearance Center at 978-750-8400, fax at 978-750-4470, or online at **www.copyright.com.**

MISSING OR LATE ISSUES
Technology Review is a monthly publication. As a new subscriber you should receive your first issue 4 weeks after your order is placed. If you are an established customer and your copy of *Technology Review* does not arrive within 4 weeks after an issue date, e-mail, telephone or write us. In either case, we'll get to the bottom of the problem and send you the missed issue. Contact us at **www.technologyreview.com/custserv/inquiry** or call 800-877-5230.

IF YOU MOVE
Send us your old and new address or visit **www.technologyreview.com/custserv/addresschange.** (Please allow 6 weeks processing time.)

AN MIT ENTERPRISE TECHNOLOGY REVIEW

MIT'S MAGAZINE OF INNOVATION
TECHNOLOGY REVIEW

EDITOR IN CHIEF
John Benditt

EDITOR AT LARGE Robert Buderi

DEPUTY EDITORS Herb Brody, David Rotman

MANAGING EDITOR Tracy Staedter

ART DIRECTOR Eric Mongeon

SENIOR EDITORS Sally Atwood, Kevin Hogan, Wade Roush, David Talbot, Rebecca Zacks

ASSOCIATE ART DIRECTOR Jessica Allen

ASSOCIATE EDITORS Erika Jonietz, Alexandra Stikeman

DESIGN ASSOCIATE Jamie Kelleher

EDITORIAL ASSISTANT Lisa Scanlon

COPY CHIEF Larry Hardesty

FACT CHECKER David Rapp

PRODUCTION MANAGER Valerie V. Kiviat

EDITORIAL INTERNS Miriam Boon, Daniel Cho, Gabriel Phifer

CONTRIBUTING WRITERS
Ivan Amato, Jon Cohen, Peter Fairley, David H. Freedman, Simson Garfinkel, Jeff Hecht, Henry Jenkins, Charles C. Mann, Michael Schrage, Evan I. Schwartz, Seth Shulman, Gary Taubes, Claire Tristram, M. Mitchell Waldrop

CUSTOMER SERVICE/ SUBSCRIPTION INQUIRIES
NATIONAL: 800-877-5230
INTERNATIONAL: 386-447-6352
www.technologyreview.com/custserv/inquiry
Cost $34 per year
Canada residents add $10
Other foreign countries add $30

ADDRESS CHANGES
www.technologyreview.com/custserv/addresschange
MIT Records 617-253-8270 (Alums only)

PERMISSIONS
978-750-8400
www.technologyreview.com/magazine/permissions.asp

REPRINTS
717-399-1900
sales@rmsreprints.com
or www.technologyreview.com/customerservice/reprints_permissions.asp

TR RELAUNCH FUND
MILLENNIAL PATRON
Robert M. Metcalfe
CENTENNIAL PATRONS
Steve Kirsch
DuWayne J. Peterson Jr.

TECHNOLOGY REVIEW
One Main Street, 7th Floor
Cambridge MA 02142
TEL: 617-475-8000 FAX: 617-475-8043
www.technologyreview.com

MIT'S MAGAZINE OF INNOVATION

TECHNOLOGY REVIEW

PUBLISHER AND CEO
R. Bruce Journey, bruce.journey@technologyreview.com

VICE PRESIDENT AND GENERAL MANAGER
Martha Connors, martha.connors@technologyreview.com

VICE PRESIDENT, SALES AND MARKETING
Kate Dobson, kate.dobson@technologyreview.com

CORPORATE

BUSINESS DEVELOPMENT MANAGER
J. R. "Matt" Mattox
matt.mattox@technologyreview.com

HUMAN RESOURCES MANAGER
Ann E. Warner

DIRECTOR OF INFORMATION TECHNOLOGY
Lon Anderson

NETWORK COORDINATOR
Scott Hendry

EXECUTIVE ASSISTANT TO THE CEO
Kelli Talbot

OFFICE ADMINISTRATOR
Eileen Cahalane

TECHNOLOGYREVIEW.COM

CONTENT MANAGER
Kristy Robinson

LEAD WEB TECHNOLOGIST
Eric Engel

STAFF EDITORS
David Cameron
Alan Leo

GRAPHIC DESIGNER
Matthew Bouchard

CONTENT AND TRAFFIC ANALYST
Thomas Pimental

SALES AND MARKETING

ASSISTANT TO THE VP, SALES AND MARKETING
Sharon Morani

ADVERTISING SERVICES COORDINATOR
Amy McLellan
amy.mclellan@technologyreview.com

RESEARCH MANAGER
Kathleen Kennedy

MARKETING COMMUNICATIONS MANAGER
Rachel Valente

CONSUMER MARKETING

DIRECTOR OF CONSUMER MARKETING
Elaine Spencer

ASSOCIATE CONSUMER MARKETING DIRECTOR
Corrine L. Callahan

CONSUMER MARKETING PROMOTIONS MANAGER
Karen Lurie

CONSUMER MARKETING ASSISTANT
Faith Welt

FINANCE

CONTROLLER
John W. Keegan

SENIOR ACCOUNTANT
John F. Leahy

ACCOUNTANT
Letitia Trecartin

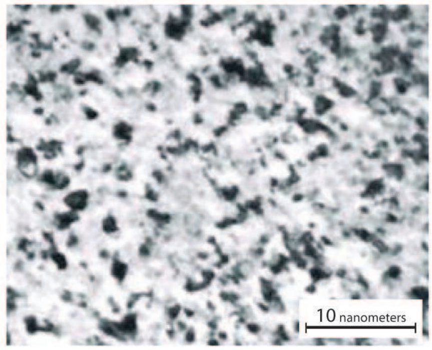
ADVERTISING SALES

NEW ENGLAND/BOSTON: 617-475-8004	Paul Gillespie	paul.gillespie@technologyreview.com
MID-ATLANTIC/NEW YORK: 212-419-2820	Alan Levine Mason Wells Jamie Casale	alan.levine@technologyreview.com mason.wells@technologyreview.com jamie.casale@technologyreview.com
SOUTHEAST/NEW YORK: 212-419-2820	Dean Grant	dean.grant@technologyreview.com
SOUTHWEST/DALLAS: 972-625-6688	Randy Artcher Steve Tierney	randy.artcher@tierney.com steve.tierney@tierney.com
MICHIGAN/DETROIT: 248-546-2222	Colleen Maiorana	colleenm@maiorana-partners.com
MIDWEST/CHICAGO: 312-629-5230	Penny Nasir	pennynasir@aol.com
NORTHWEST/SAN FRANCISCO: 415-659-2980	Merrick Musolf Sam Staley	merrick.musolf@technologyreview.com sam.staley@technologyreview.com
SOUTHERN CALIFORNIA/LA: 310-451-5655	Gregory Schipper	gschipper@whiteassociates.com
AUSTRIA AND GERMANY: 49-89-9392-6711	Guido Klausbruckner	gklausbruckner@web.de
HONG KONG: 852-2516-1001	Wendy Lin	wlin@publicitas.com
EUROPE: 44-207-630-0978	Anthony Fitzgerald David Wright	afitzgerald@mediamedia.co.uk dwright@mediamedia.co.uk
JAPAN: 813-3261-4591	Shigeru Kobayashi	shig-koby@media-jac.co.jp

PROTOTYPE

STRAIGHT FROM THE LAB: TECHNOLOGY'S FIRST DRAFT

FASTER THAN FLASH



Material stores bits as areas with electrical resistance that is low (shown here) or high.

"Flash" memory uses so little power that designers have built it into hundreds of portable devices, from digital cameras to handheld computers. But flash memory has its flaws: it's slow at storing new data, and it wears out after only about a million read/write operations. Now Intel is testing a new kind of memory chip that it says will outpace and outlast flash—and still save power.

The new chip is based on work pioneered by inventor Stanford Ovshinsky, CEO of Rochester Hills, MI-based Energy Conversion Devices. Heat from an electric current switched by a diode alters the electrical resistance of tiny pockets of a germanium-tellurium-antimony alloy on the chip; pockets with changed or unchanged resistance represent digital ones and zeroes. Intel's latest test version of the chip stores four megabits, lasts through a million times as many operations as flash memory, and writes data a thousand times faster—almost as fast as conventional memory. While Intel researchers say it will be three to five years before the technology finds its way into products, future cameras, handhelds, cell phones and other devices equipped with the new memory could store digital information much faster and more reliably—and might be cheaper, too, since the new memory can be etched onto a silicon wafer right alongside other circuitry.

FEWER BITS, BETTER CODE

As new security regulations pile more tedium onto the airline boarding process, a Burlington, MA, startup called Ntru hopes its encryption technology can help keep queues flowing. The company's software lets makers of embedded microchips incorporate data encryption directly into their silicon. The company's algorithms use eight-bit numbers, versus the several-hundred-bit numbers employed by today's standard encryption systems. These smaller numbers mean the technology can encrypt data faster; yet the company claims it can provide the same level of protection. The software could eventually underpin secure luggage tags and wireless code readers that authenticate passengers and link them to their baggage. It may also help inexpensive chips lock unauthorized users out of cell phones, pagers or payment cards. Ntru's technology should be on the market by year's end.

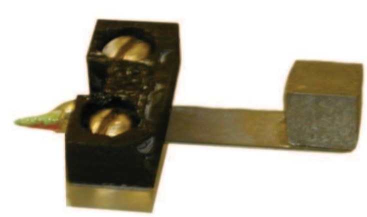
SMARTER STORAGE

Permabit, a Cambridge, MA, startup, is bringing software to market that could revolutionize the way organizations store and access data. The software automatically distributes files among computers at different company locations, with just enough duplication to assure business continuity in case of physical disaster. When someone modifies a file, the system resaves only those sections of it that have changed, lowering the demand for transmission bandwidth. The data is encrypted such that it is impossible to trace to its creator—protecting the system administrator from potential legal liability and maintaining user privacy. Designed to provide backup storage as well as management of "live" data, the system will allow companies to dispense with slow and expensive storage tapes. The technology is expected on the market late this summer.

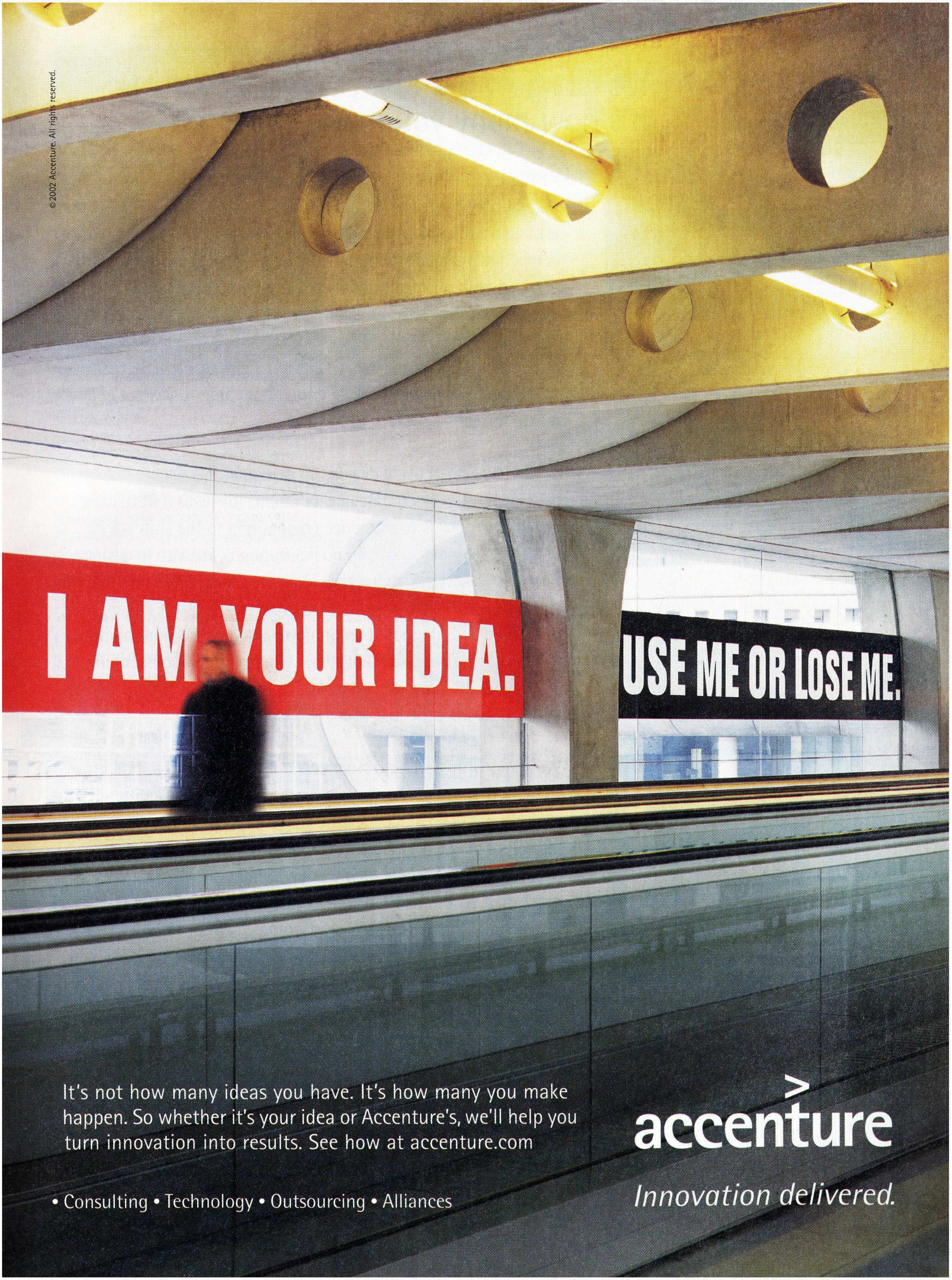
VIBRATIONAL PARASITES

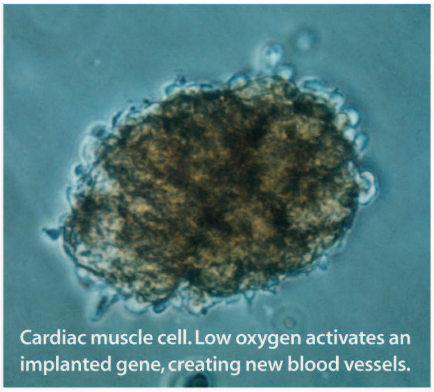
The typical building never stops shaking. Air conditioners, heaters and even computer fans vibrate the walls, floors and ceilings. University of California, Berkeley, researchers are working on tiny wireless devices that scavenge this continual buzz as a source of power. The devices attach to surfaces throughout a building to monitor conditions such as airflow and temperature, and contain transceivers that send data to a central computer that can adjust the climate.

Better than batteries because it doesn't run down, and more practical than wall wiring, the device's power scavenger uses a piezoelectric material and a weight attached to a springy cantilever *(photo)* to convert mechanical pressure into electricity. Berkeley mechanical engineering graduate student Shad Roundy has built quarter-sized scavengers that generate 70 to 80 microwatts—enough to run a sensor and transceiver—and aims to demonstrate more-powerful devices by year-end.



COURTESY OF THE UNIVERSITY OF CALIFORNIA, BERKELEY (VIBRATIONAL PARASITES); VITO ALUIA (ILLUSTRATION); COURTESY OF OVONYX (FLASH)


I AM YOUR IDEA.
USE ME OR LOSE ME.
It's not how many ideas you have. It's how many you make happen. So whether it's your idea or Accenture's, we'll help you turn innovation into results. See how at accenture.com
• Consulting • Technology • Outsourcing • Alliances
accenture
Innovation delivered.
© 2002 Accenture. All rights reserved.



Cardiac muscle cell. Low oxygen activates an implanted gene, creating new blood vessels.

SWITCHABLE GENES

Many genes that exist naturally in the body turn on and off when needed; otherwise they would crank out superfluous proteins nonstop. But the artificial genes that are injected to treat disease generally are simpler constructs and are always "on," starting protein production soon after they reach the bloodstream. Now, researchers at SRI International in Menlo Park, CA, have constructed an artificial gene with an "off" switch.

SRI's experimental gene directs the production of proteins responsible for growing new blood vessels. Persistent low levels of oxygen in cardiac muscle—often an early warning of clogged blood vessels that can cause heart attack—turn the gene on, initiating the production of blood vessels. Over time, these new vessels remedy the oxygen shortage. When the oxygen level returns to normal, the gene switches "off." SRI has secured two patents on the unique DNA sequence that acts as the gene's switch.

TINY TAGS

Radio frequency identification tags are popping up in everything from windshield toll-paying units to inventory-tracking aids on warehouse pallets. A 250-micrometer-wide tag developed at Sarnoff in Princeton, NJ, is the smallest ever *(photo)*. Its antenna is etched in silicon alongside photocells, logic and 50 bits of memory—enough to code billions of different ID numbers. Costing just pennies each, these microtags broadcast their IDs after receiving a burst of laser energy. Princeton-based PharmaSeq, which hired Sarnoff to develop the device, will initially use it for medical diagnostics. PharmaSeq coats the microtags with DNA sequences from known diseases, then mixes the tags with blood samples labeled with fluorescent dyes. Tags are routed through an optical reader; the ID numbers of any glowing tags provide a diagnosis. Sarnoff's Jonathan Schepps sees the tags being used to track small, valuable items, like money or gems—or to "covertly label things."

BREAKING THE ICE

Imagine a winter in New Hampshire without ever having to scrape ice from your windshield. Dartmouth College engineering professor Victor Petrenko has developed a deicing technology that runs off a car battery—potentially making that bit of cold drudgery a thing of the past. Embedded in a car windshield are electrodes made of indium tin oxide (a transparent conductor). A power converter transforms the car battery's direct current into high-frequency alternating current, which heats the ice much the way microwaves heat water. Unlike conventional windshield defrosters, Petrenko's system heats just the ice, not the windshield. The system is much faster and more effective than conventional defrosters and uses a tenth the energy. Petrenko is developing deicers using similar technology for the interiors of freezers. Dartmouth has licensed the deicing technology to Torvec, a Pittsford, NY, developer of off-road tracked vehicles; vehicles using the deicer should be on the market within two years.

COOL RAYS

X-ray machines have changed little over the century: a metal filament heated to 1,500 °C in a glass vacuum tube shoots out electrons that hit a piece of metal, generating the radiation that travels through flesh but not bone. Physicist Otto Zhou at the University of North Carolina has come up with a cooler way to make x-rays. Zhou replaces the filament with carbon nanotubes—large, pipelike carbon molecules. Exposure to a weak electric field causes the nanotubes to emit electrons, which in turn produce x-rays the conventional way and make images such as the one shown. Because the whole process can take place at room temperature, there's no need for heavy equipment to heat up the electron source. Nanotube-based x-ray machines can therefore be much smaller than conventional ones, making portable devices possible. To commercialize the technology, Zhou cofounded Applied Nanotechnologies in Chapel Hill, NC. The company aims to have its first product on the market within two years.

SPY, THEN INNOVATE

In *A Primate's Memoir*, Stanford University neuroscientist Robert Sapolsky recalls how a generous army donation of surplus night goggles utterly transformed the field of carnivorology. The ability to see in the dark revolutionized how zoologists saw scavengers, predators and prey, which ultimately led to dramatic reversals in our characterizations of the animal kingdom.

Thus, Sapolsky writes, "Redemption of the hyenas. It turns out that they are fabulous hunters, working cooperatively, taking down beasties ten times their size. They have one of the highest percentages of successful hunts of any big carnivore. And you know who has one of the worst? Lions. They're big, conspicuous, relatively slow. It's much easier for them just to key in on cheetahs and hyenas and rip them off. That's why all those hyenas are lurking around at dawn looking mealy and unphotogenic—they just spent the whole night hunting the damn thing and who's eating breakfast now?"

That new instruments can enable new insights is hardly a revelation. The surprise is that these technologies have been better employed explaining animal behavior on the African savannah than exploring human behavior in more corporate environments. Just as night vision revealed the king of the jungle to be more scavenging bully than noble hunter, techniques such as network monitoring of software systems and video-based surveillance of employees at work can give innovators provocative perspectives on the predator, prey and scavenger relationships of their own customers.

For example, a medical device company (which understandably wants to remain anonymous) decided to surreptitiously videotape, with hospital administrators' permission, how nurses actually used its prototype drug delivery system. The company quickly recognized that its product wasn't being used the way it was supposed to be. Moreover, it discovered what kind of shortcuts the nurses would take—creative and otherwise—to get the system to work, and at what points they would either ask for help or simply give up. This information proved enormously helpful and led to a fundamental redesign of both the product and how hospital staffs are trained to use it. That, in turn, completely changed how the company marketed its systems to hospitals and nurses. The firm has yet to decide whether to make video surveillance an ongoing practice.

"Innoveillance"—think of it as "next-generation" market research—isn't merely a function of bandwidth. Vision here means deciding what kind of innovation behaviors *should* be observed. What customer behaviors matter? How can technology give innovators a window onto the adoption and adaptation of their offerings? In practically every realm of innovation, opportunities exist for clever ways of capturing customer behavior in the wild. We'll talk about privacy later.

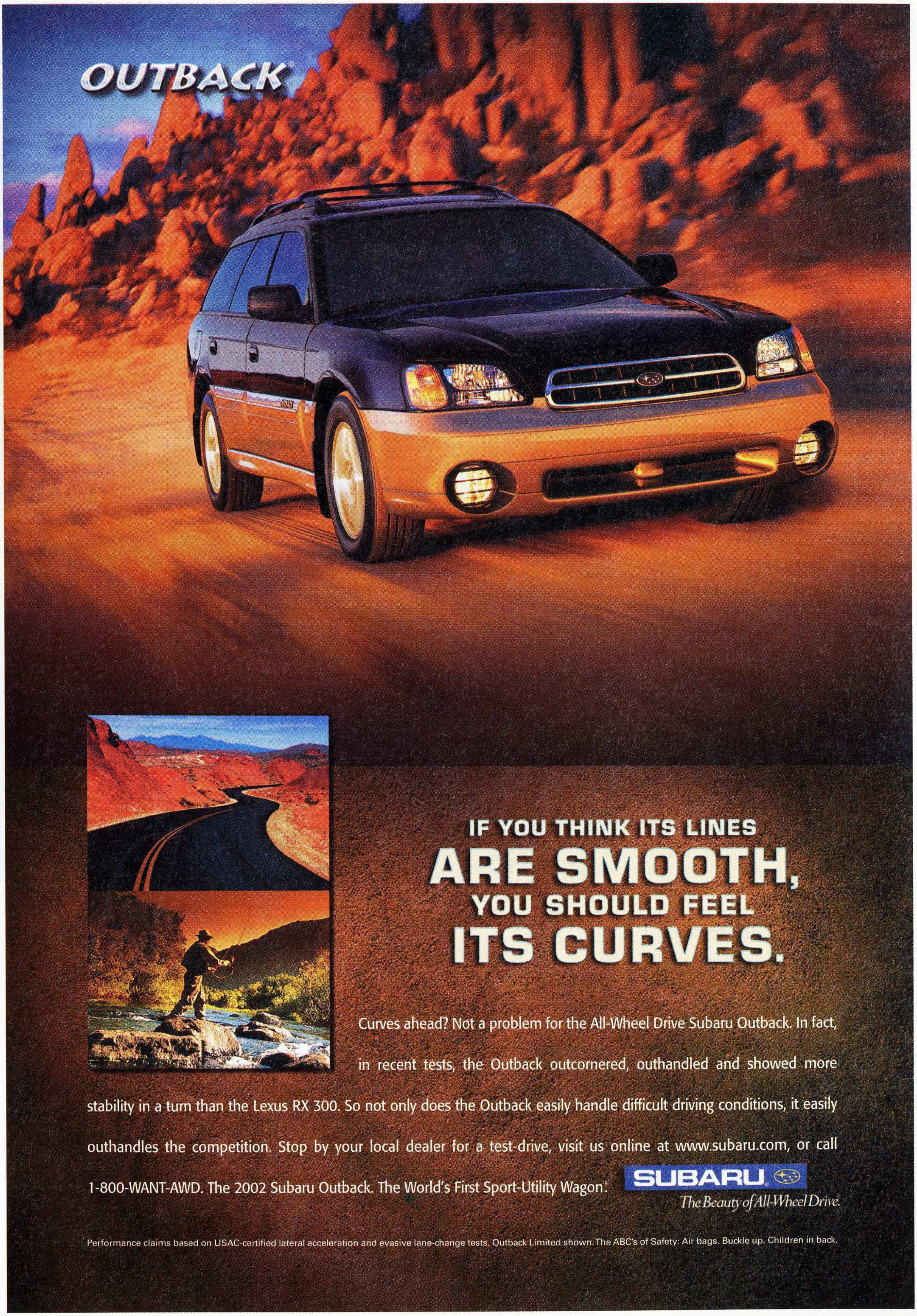
Look at how software is now evaluated, for instance. Empirically, it's clear that most software adheres to the "80/20" rule—that is, roughly 20 percent of the features and functions generate 80 percent of the usage. Similarly, approximately 20 percent of the code is responsible for 80 percent of the problems. These distributions are well known in software-engineering circles. Yet surprisingly, most *Fortune* 500 companies don't really know the "80/20" drivers of their own software usage. While many firms track glitches, bugs and crashes, they're frequently unaware of which features and functions are used most often. Indeed, even software innovators are remarkably ignorant of how their code is actually used.

Software innovators and their more introspective customers may be better off using "remote diagnostics"—spy technologies that capture workers' activity in the natural environment—to anticipate customer use, instead of tabulating system crashes. How do users actually use new technology or follow new practices? What innovative new products, services and upgrades might these patterns suggest?

New surveillance techniques such as network-monitoring software can give innovators provocative perspectives on the predator, prey and scavenger relationships of their own customers.

The same questions apply to products ranging from jet engines to automobiles to cell phones to personal computers to telecom networks to machine tools. Emerging infrastructures enabling remote diagnostics, combined with the ability to monitor and simulate usage patterns, create the corporate counterparts of night vision. Companies can actually choose what level of innoveillance makes sense for them. Innoveillance-generated insights are what will give innovators awareness of how their ideas are actually adopted. Market research, which is compiled by asking people in surveys or focus groups how they behave, blurs into jumbles of demographic statistics. Traditional maintenance becomes a medium for novel upgrades that serve no real purpose.

Do nurses, doctors, airplane pilots and white-collar workers want to have their keystrokes captured and their movements recorded? Probably not. Do questions of privacy and proprietary use have to be negotiated anew? Of course. Innoveillance represents yet another battleground where innovators and their customers will clash over the future of value creation. But the fundamental observation remains the same: the ability to intelligently discriminate between how people actually behave and how they are supposed to behave is critical to understanding how ideas spread. The marginal cost of providing that kind of vision is declining; the marginal value of having that kind of vision is climbing. You can't see what you're not looking for. Open your eyes.


OUTBACK®
IF YOU THINK ITS LINES
ARE SMOOTH,
YOU SHOULD FEEL
ITS CURVES.
Curves ahead? Not a problem for the All-Wheel Drive Subaru Outback. In fact, in recent tests, the Outback outcornered, outhandled and showed more stability in a turn than the Lexus RX 300. So not only does the Outback easily handle difficult driving conditions, it easily outhandles the competition. Stop by your local dealer for a test-drive, visit us online at www.subaru.com, or call 1-800-WANT-AWD. The 2002 Subaru Outback. The World's First Sport-Utility Wagon.®
SUBARU®
The Beauty of All-Wheel Drive.®
Performance claims based on USAC-certified lateral acceleration and evasive lane-change tests. Outback Limited shown. The ABC's of Safety: Air bags. Buckle up. Children in back.

AUTOMATIC NETWORKS

Devices that connect themselves could change networking

You've spent the last several weekends hunting for the perfect lamp to brighten up that shadowy corner of the living room. When you finally bring it home and plug it in, the network of motion sensors and light meters in the house immediately senses the torchière and turns it on—but only if it's dark and you're in the room. And if you decide to swap it with the lamp in the bedroom, no problem: the network figures that out as soon as you're done.

In theory, linking together sensors, appliances and other devices so they can communicate and work together could make life easier and more productive. The reality—at least for now—is that setting up such networks is expensive and far from easy, especially if they involve thousands or even millions of components.

Now networks of devices that organize themselves—connecting to one another wirelessly and automatically, without human intervention—are moving out of research labs and into the marketplace. In their first incarnation, they will connect large numbers of sensors in factories and industrial settings, but within a few years they will move into office buildings, homes, even farm fields. Companies like MIT Media Laboratory spinoff Ember, Motorola and San Diego-based Sensoria are moving to create and sell the wireless radios and microchips that will enable devices ranging from temperature sensors to sprinklers to be connected in self-organizing networks [*Technology Review* board member Robert Metcalfe is an Ember investor and board member. Ed.]. "It really is the only form of networking that can work for lots and lots of little objects," says MIT Media Lab researcher Michael Hawley. "The consequences of it really are going to be as magical as anything we've seen in technology."

In a self-organizing network, says Ember cofounder and chief technology officer Rob Poor, "You just plunk these nodes down, and they discover each other and figure out how to get data back to where you want to get it to." In other words, every element automatically recognizes every other element. Without any outside help, the devices must then determine how to get data where it needs to go.

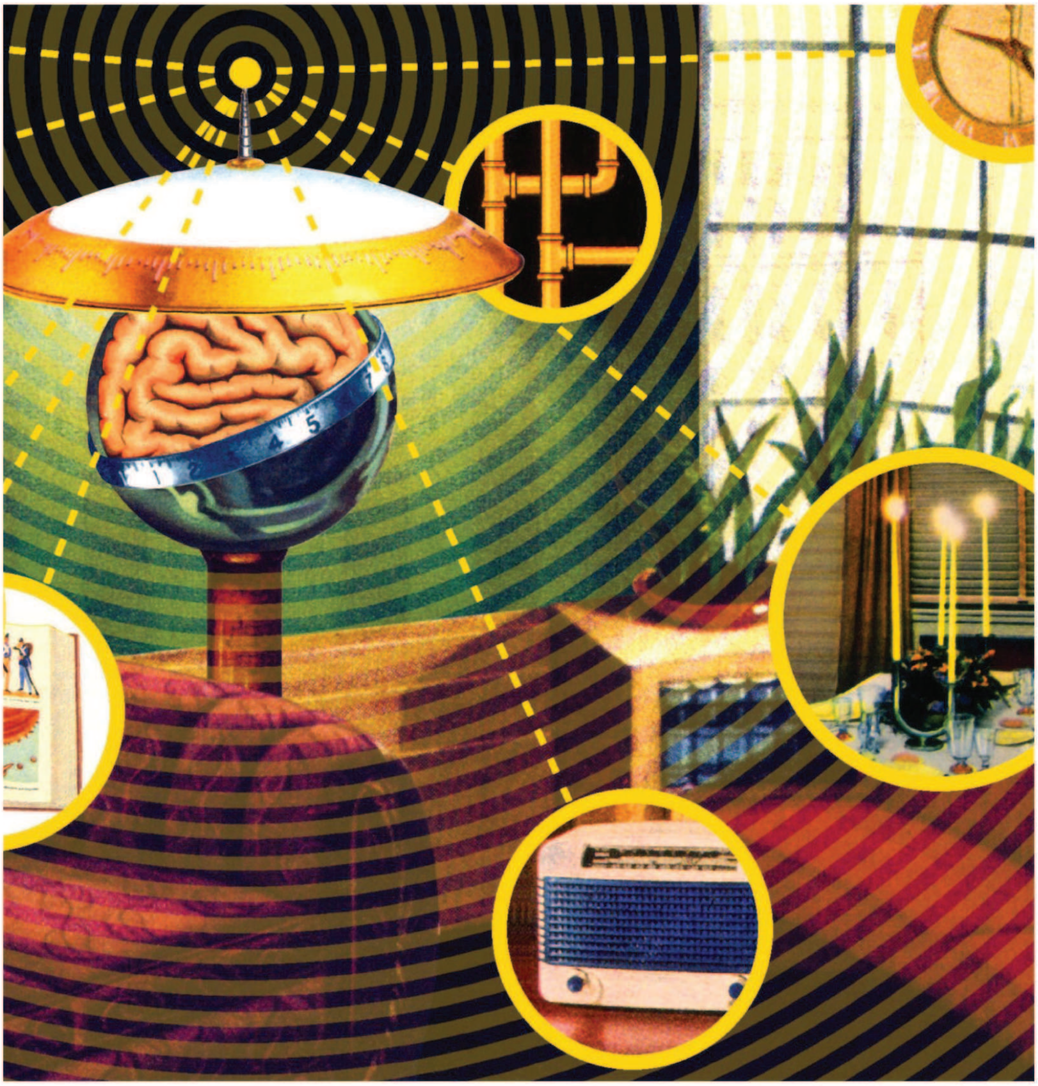
One self-establishing network that is slowly making commercial headway is the Bluetooth wireless system. Originally designed by cell phone maker Ericsson to replace cables running between devices like computers and printers or cell phones and headsets, the system allows up to eight devices to connect to each other. When any device equipped with a low-cost Bluetooth radio comes within about 10 meters of any other Bluetooth-enabled product, the two automatically initiate a connection.

"Bluetooth is pretty well designed for what it was supposed to do, which was allow all the devices you carry around to talk to each other," says Ember cofounder and chief scientist Andy Wheeler. But the eight-device limit and the design of the Bluetooth network both hinder the system's usefulness for applications that require hundreds or thousands of devices spread over a large area.

Most wireless networks, including Bluetooth and the popular 802.11b "Wi-Fi" networks used to connect computers to the Internet, employ a spoke-and-hub organization in which one device acts as a central access point that all the other network members must communicate with directly. This turns out to be impractical in settings like factories, which are filled with machines, thick concrete walls and other radio-hostile things. That's where Ember and similar network designs come in. With Ember's networking protocols, the radio networks look like a mesh: every device recognizes other nearby devices immediately and can talk to all of its neighbors, passing data along. "Every

SOME COMPANIES IN SELF-ORGANIZING NETWORKS

COMPANY	APPLICATION
Sensoria (San Diego, CA)	Home and office building automation; automotive applications
Motorola (Phoenix, AZ)	Wire replacement for factories; home and office building automation
Palo Alto Research Center (Palo Alto, CA)	Military applications and homeland defense
MeshNetworks (Maitland, FL)	Cellular replacement for mobile broadband voice and data services



JOHN CRAIG

The applications of self-organizing networks, says the MIT Media Lab's Michael Hawley, "really are going to be as magical as anything we've seen in technology."

node is a little bit of a router," says Poor. "It sends the message on in the right direction."

The initial application of Ember networks will be the replacement of expensive wiring in areas like factory floors. Other uses for the system will emerge as prices drop. For example, temperature, light and motion sensors could be placed in office buildings and networked to the lighting and ventilation systems. The network would then be able to tell when people were working in different areas of the building and switch on lights, heating or cooling only when needed. The same idea will eventually be applied to home automation, says Ember's acting CEO Adrian Tuck. Tuck cites security systems as another emerging application. For example, networked biological-weapons sensors placed in air-conditioning ducts throughout a building or in water treatment plants could offer early warning of a terrorist attack *(see "Networking the Infrastructure,"* TR *December 2001).*

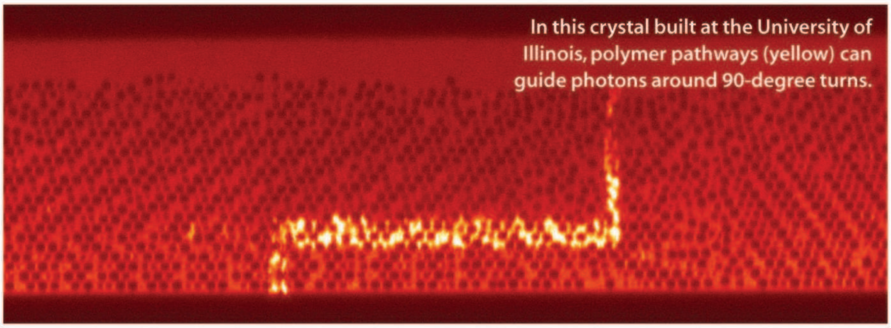
Motorola researchers see agricultural applications as well. Moisture sensors distributed throughout a field could be networked to irrigation systems, signaling the giant sprinklers to activate only when a part of the field was dry, instead of at regular intervals, saving water and money. The same scheme might be employed in a backyard sprinkler system.

Self-organizing architectures are also appearing for more complex networks. Engineers at IBM's Almaden Research Center in San Jose, CA, are prototyping a data storage system made up of "collective intelligent bricks": densely packed devices each consisting of a microchip, some memory and several hard-disk drives. Several hundreds of the bricks would be combined to create a single massive storage system. Software allows the bricks to recognize the addition of new bricks and figure out the best way to send data between them for storage. Similarly, if a brick fails, the system finds a way to route around it.

The goal of the brick system is to make storage servers simpler and cheaper to manage. Moidin Mohiuddin, the lab's senior manager of advanced storage systems, estimates that one administrator can currently manage about one terabyte, or one trillion bytes, of data. He hopes a system composed of the bricks could increase that figure a thousandfold. Moidin says the architecture could work as well for other types of servers and ultimately even PCs, making setting up a home or office network as simple as turning on the machines.

As they make their way into more and more systems, self-organizing networks will do no less than transform the way we relate to everything from our computers to our appliances, making them, if not smarter, at least more helpful. "I think [the networks] will turn up in all sorts of creative ways," says MIT's Hawley. "The result is going to be a radical simplification of the way we interact with the stuff around us."

—Erika Jonietz


In this crystal built at the University of Illinois, polymer pathways (yellow) can guide photons around 90-degree turns.

GUIDING LIGHT

PHOTONICS | To Paul Braun, the future of optical computing is crystal clear. Braun and his colleagues at the University of Illinois at Urbana-Champaign report that they've found a cheaper and simpler way to construct tiny optical "waveguides" inside photonic crystals. These waveguides have the potential to behave like the microscopic wires on a conventional microchip, except that they would transport photons rather than electrons around tangles of sub-micrometer-scale circuitry. And that could help make photonic crystals the basis for a new generation of far faster telecommunications and computing devices.

Photonic crystals are intricate microscopic structures pocked with regularly spaced holes, like an orderly Swiss cheese. The holes create a barrier against light of certain wavelengths, and in the right arrangement, they can force photons along prescribed paths. Unlike optical fibers, which leak light when bent too far, these waveguides can hurl photons around sharp corners, making them ideal components for optical switches, microlasers, light-emitting diodes, even all-optical integrated circuits.

While companies like Agilent Technologies and a number of academic and government labs are developing photonic crystals, creating pathways that snake through them with the required micrometer-level precision is a major challenge. Several research groups, including one at Sandia National Laboratories in Albuquerque, NM, have built and tested photonic-crystal waveguides on silicon wafers, but their fabrication technique is the same complex, repetitive and expensive lithographic process used to pattern today's microchips. "It's a wonderful technique—if you don't care what it costs," Braun says.

Braun's technique starts with tiny silica spheres that assemble themselves in solution into a three-dimensional, crystal-like structure. Braun's real achievement was finding a way to create precisely shaped pathways through these crystals after they assemble: his group fills the space between the spheres with a photosensitive polymer, then uses a microscope to focus a laser on specific points, causing the polymer to harden. Drain the surrounding, unhardened polymer, and the result is a "defect" in the crystal: a perfectly sculpted pathway through the spheres, built with only one pass of the laser.

"A lot of people have been thinking about how to add defects to these self-assembling materials," says David Norris, a photonics researcher in the Chemical Engineering and Materials Science department at the University of Minnesota. "Paul's group has shown the first example of how that might be done." While Braun says it could take three years or more for self-assembling photonic crystals to find their way into commercial devices, he expects to demonstrate a working prototype—perhaps made from a material such as silicon that transmits light more reliably than the polymer—within the next six months. —*Wade Roush*

SPEEDIER DELIVERY

LOGISTICS | **In an effort to reduce futile delivery efforts and the stranding of valuable packages on front porches, researchers at Accenture Technology Labs in Chicago are developing a Web-based software system for package shipping and receiving.**

When a package reaches a certain point in shipping—say, the regional hub where trucks are loaded for local routes—it's scanned and identified much as parcels tracked by United Parcel Service and Federal Express are now. The software then sends out an alert to the package's recipient, based on preferences he or she has preselected online: e-mail, an instant text message or a phone call. A customer can even grant the shipper access to an online personal calendar in order to coordinate a preferred delivery time and can send the system new delivery instructions if the original time or address is inconvenient. The software automatically updates the driver's delivery list, saving the precious time it takes to drive to an empty home and write a missed-delivery note.

Accenture's package delivery system can confirm a recipient's identity using a portable fingerprint reader.

While Accenture will not divulge which of its corporate clients are interested in the prototype, the researchers foresee widespread use of the software within a few years. And since the system is built using universal Web standards, says Michael Hoch, analyst at the Boston-based Aberdeen Group, "You can expect to see any number of companies develop similar services in the next three to five years." Which could mean the end of those dreaded missed-delivery sticky notes once and for all. —*Kevin Hogan*

SPEAK EASY

IBM aims to solve speech recognition's nagging problems

SOFTWARE | The idea of computers that accurately understand human speech has both enticed and frustrated engineers. But now, IBM Research in Yorktown Heights, NY, is undertaking a multiyear project to finally solve all the problems that have kept voice recognition systems from comprehending free-form conversations—and becoming mainstream technology.

IBM aims to create a system that understands perhaps 20 languages, including medical and legal terms, with about 98 percent accuracy—a big improvement over the 80 to 85 percent accuracy of IBM's own speech recognition products and those from firms such as Peabody, MA-based ScanSoft. Troubles with accuracy are largely to blame for the limited market for speech recognition, which has so far been relegated mainly to dictation and telephone-based automated-response applications. IBM also hopes to overcome the other limitations of current systems: the need for hours of training, quiet surroundings and steady voice inflections. By making voice recognition more accurate and more broadly applicable, IBM believes it could open markets in real-time transcription for business meetings and new voice interfaces for handheld computers, or for search engines that could retrieve sound bites from audio databases of news broadcasts and speeches.

In current speech recognition technology, algorithms compare the waveform, an electronic representation of a word, to a master waveform database to develop a short list of possible matches, then select the most commonly used word on that list. IBM is exploring ways to make better matches, including new algorithms that make guesses based on the context of the conversation. IBM researchers have also built a lip-reading video system that reduces errors by one-third, says David Nahamoo, group manager of Human Language Technologies for IBM Research. "We're combining audio and visual features together, which we're feeding into our recognition engines," he says. "We're learning how to use one to clean up the other."

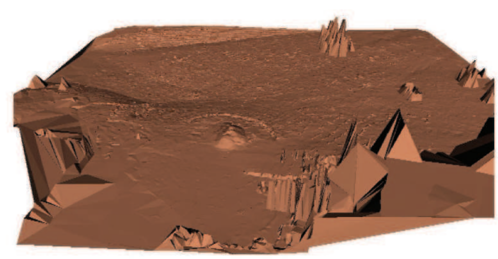
Some experts are skeptical. Real-time meeting transcription is still "lab stuff right now," says Steve McClure, vice president at technology market researcher IDC in Framingham, MA. "I've seen IBM demos work fine one time, and another time the damn application wouldn't work at all." Nahamoo concedes the initiative needs years of work and lots of luck to reach its goals. But given the speech recognition industry's history of failing to deliver on its promises, Big Blue's newest push could provide a few words of encouragement to the struggling technology. —*Alan Joch*

HIGH-TECH DIRT PILES

CONSTRUCTION | Keeping accurate tabs on every element of a construction project, from piles of earth to stacks of steel beams, is complicated and expensive. To ease the burden on builders, engineers at the National Institute of Standards and Technology are developing information networks that could automate the process.

In one experiment, a construction site is rigged with a Global Positioning System antenna, a computer equipped with a wireless Ethernet connection and a laser-based measuring device. The laser scanner analyzes the size of an object—say a mound of excavated dirt; measurements are sent via wireless Ethernet to databases and file servers that can be accessed by contractors and engineers both on and off the site. Software puts the data into an intelligible form—say, a 3-D model for monitoring job status—and can provide precise measurements for billing purposes. "Right now, many estimates for jobs like ground removal are taken only by how many trucks were used to haul the stuff away," says Geraldine S. Cheok, a research structural engineer at NIST. "This will make the numbers much more exact."

Ultimately, the NIST system would go beyond measuring dirt piles. Researchers plan to use radio frequency identification tags to track every pipe, beam and hammer that enters or leaves a site. While the researchers expect to have the technology ready for field use by 2006, the building industry is notoriously slow in adopting new techniques, says Ken Eickmann, director of the Austin, TX-based Construction Industry Institute, a research organization that looks for better construction practices. "But if it proves to be a cost saver," he says, "you will see it in practice." —*Kevin Hogan*



NIST's system generates a 3-D model of a construction site's terrain before excavation.

COURTESY OF THE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY (DIRT PILES); JAMES YANG (ILLUSTRATION)

BIOTECH COMPUTING OPENS UP

An African firm turns to open-source programming

SOFTWARE | Open-source programming created a revolution in operating systems, making Linux a popular alternative to Microsoft's Windows. The idea—to make software source code open for modification by anyone—has caught on in large part because more eyes on the software means rapid improvements and fewer bugs; companies like Red Hat have turned the idea into profits by selling easily installed, well-supported versions of Linux. Now Cape Town, South Africa-based Electric Genetics is, for the first time, applying that business model to biomedical software.

In June, Electric Genetics plans to launch its first open-source product, a package of programs that link human DNA sequence data to information about how and when genes are turned on, and about the proteins encoded by those genes. "The science behind genomics is changing weekly," says cofounder Tania Broveak Hide. "A commercial software company, with your typical 12- to 18-month development cycle—I really don't think that works for a fast-moving scientific discipline."

Broveak Hide and her husband Winston Hide—the University of the Western Cape bioinformaticist with whom she cofounded the company in 1997—reached that conclusion after first selling proprietary software—and after their own programmers suggested that open-source development would yield better software faster. "I think it'll make a huge difference for the scientific discoveries," says Broveak Hide. "If we can push out better technology to the pharmaceutical companies, they're going to be able to make their discoveries faster."

Though others have yet to follow Electric Genetics' lead, industry observers say open-source development will be critical to improving the quality of bioinformatics software and, ultimately, biomedical research. —*Erika Jonietz*

A BETTER VIEW FOR ADVANCED SURGERY

MEDICINE | **The advent of "minimally invasive" surgery, performed with slender instruments through tiny incisions, has meant less trauma and faster healing for patients. But the technique requires surgeons to watch a video or ultrasound screen while operating to see what's going on underneath the skin—an awkward proposition for the surgeon. A head-mounted virtual-reality apparatus, developed at the University of North Carolina and now in clinical trials, could offer doctors a more natural view and allow for faster, safer operations.**

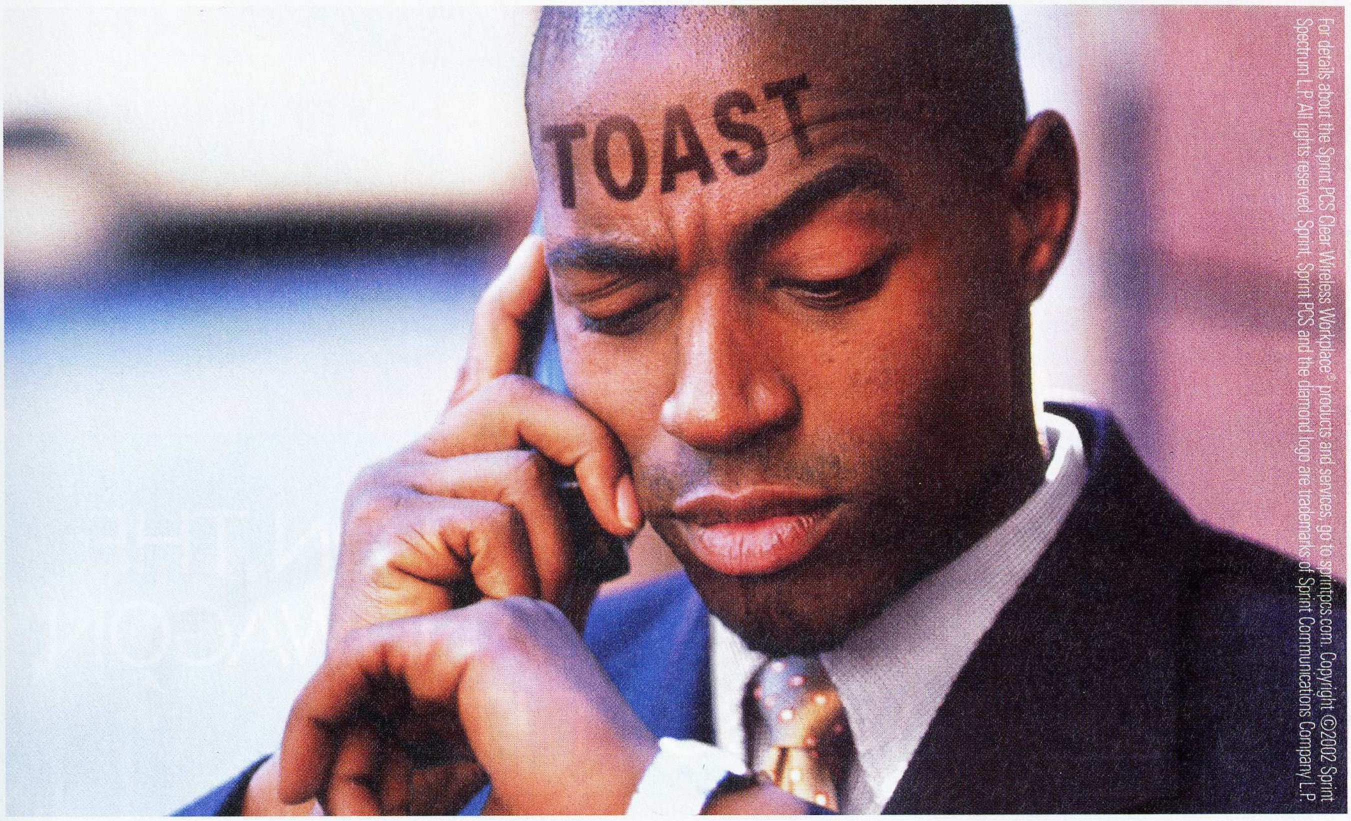
The trial—the first conducted with such a device—will involve 24 women undergoing breast tissue biopsies. A surgeon dons headgear incorporating glasses-like displays and two cameras mounted in front of her eyes. A computer merges ultrasound information flowing from a probe held to the patient's skin with video taken by the cameras, showing the operation site. This combination gives the surgeon a view into the body that corresponds with her natural perspective. What's more, the system tracks every twist and turn of the surgeon's head using ceiling-mounted cameras. Software adjusts for these movements to keep the ultrasound and video components of the surgeon's view in sync.

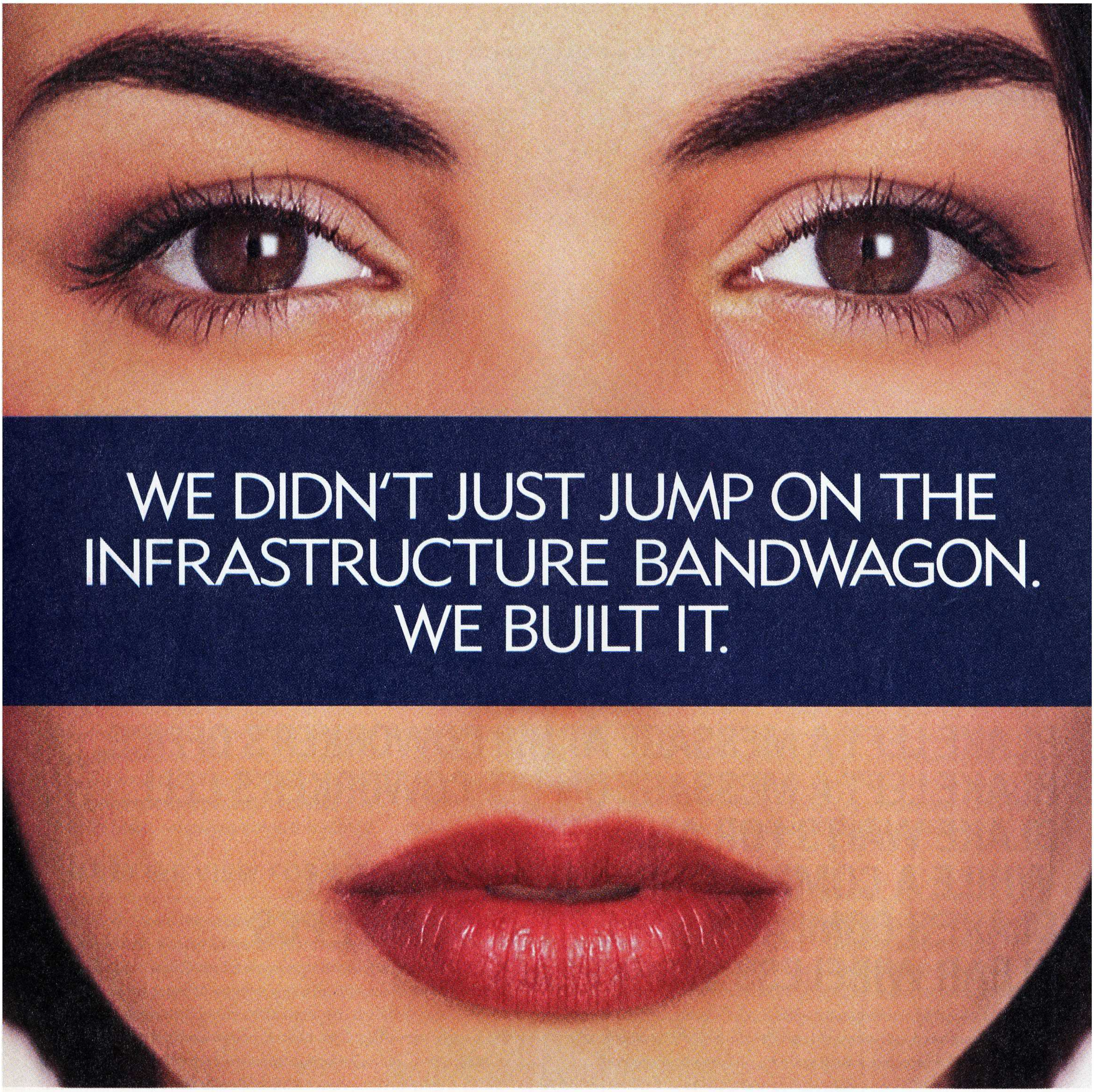
University of North Carolina engineer Kurtis Keller helped build this surgical visualization device.

Harvard Medical School's Ferenc Jolesz, director of image-guided therapy at Boston's Brigham and Women's Hospital, says the North Carolina device "may lead to fundamental change in surgical visualization." The technology does, however, have competition. Siemens is developing a similar device and is now seeking an appropriate clinical trial.

The North Carolina device might take a decade to reach operating rooms, says computer scientist Henry Fuchs, who led the team that developed it. So far, a surgeon working with Fuchs has performed four operations; Fuchs hopes that others will be completed this year. After that, he aims to seek an industrial partner to further develop the technology. Eventually, head-mounted devices could be used for more challenging procedures like liver biopsies, which would become less awkward for surgeons—and safer for patients. —*David Talbot*

ANDREI STATE (BETTER VIEW); JAMES YANG (ILLUSTRATION)


TOAST
For details about the Sprint PCS Clear Wireless Workplace® products and services, go to sprintpcs.com. Copyright ©2002 Sprint Spectrum L.P. All rights reserved. Sprint, Sprint PCS and the diamond logo are trademarks of Sprint Communications Company L.P.



It's time to set the record straight. Long before our competitors even added the word "infrastructure" to their vocabulary, we were busy creating it. Since we first launched Unicenter®, it has become the de facto global standard for managing eBusiness infrastructure. But we didn't stop there–we're also the world leader in security and storage software. Every day, our software handles over 180 million transactions, protects $50 billion in wire transfers and stores 40 million security exchanges. Expertise doesn't happen overnight. It's taken 25 years of hard work and leadership to get to be the best. So when we say you can trust every one of our 18,000 employees around the world to deliver the software and service that your eBusiness' success depends on, we really mean it.

ca

Computer Associates™

HELLO TOMORROW | WE ARE COMPUTER ASSOCIATES | THE SOFTWARE THAT MANAGES eBUSINESS™

ca.com

PROGRAMMABLE CHIPS

Reconfigurable hardware could change everything

Late for an appointment, you grab your "personal information appliance." Prompted by your uttering the words "cell phone," the small gadget awakens and instantly programs itself for a mobile phone call. Done with the call, you say "translator," and the device rewires itself to translate the latest business news from Tokyo. Issue the command "map," and it reconfigures itself again to take a GPS reading and display your location in real time.

One reason that this type of versatility is not possible today is that handheld gadgets are typically built around highly optimized specialty chips that do one thing really well. These chips are fast and relatively cheap, but their circuits are literally written in stone—or at least in silicon. A multipurpose gadget would have to have many specialized chips—a costly and clumsy solution. Alternately, you could use a general-purpose microprocessor, like the one in your PC, but that would be slow as well as expensive. For these reasons, chip designers are turning increasingly to reconfigurable hardware—integrated circuits where the architecture of the internal logic elements can be arranged and rearranged on the fly to fit particular applications.

Dozens of academic research groups and startup companies are pursuing the ideal of the reconfigurable computer *(see table)*. One of the most promising approaches is a technology called "field-programmable gate arrays." The strategy is to build uniform arrays of thousands of logic elements, each of which can take on the personality of different, fundamental components of digital circuitry; the switches and wires can be reprogrammed to operate in any desired pattern, effectively rewiring a chip's circuitry on demand. A designer can download a new wiring pattern and store it in the chip's memory, where it can be easily accessed when needed. "This kind of reconfigurable logic is grabbing a larger and larger share of designs," says physicist Philip Kuekes of Hewlett-Packard Laboratories. "And it will get even bigger."

Basic reconfigurable circuits already play a huge role in telecommunications. For instance, relatively simple versions made by companies such as Xilinx and Altera are widely used for network routers and switches, enabling circuit designs to be easily updated electronically without replacing chips. In these early applications, however, the speed at which the chips reconfigure themselves is not critical.

To be quick enough for personal information devices, the chips will need to completely reconfigure themselves in a millisecond or less. "That kind of chameleon device would be the killer app of reconfigurable computing," says University of California, Berkeley, computer scientist John Wawrzynek. And Wawrzynek and other computer scientists believe that it could soon be within reach, as they continue to improve the speed and density of reconfigurable logic circuits. These experts predict that in the next couple of years reconfigurable systems will be used in cell phones to handle things like changes in telecommunications systems or standards as users travel between calling regions—or between countries. Wawrzynek says the technology's biggest impact may be that it allows devices to better handle streaming media.

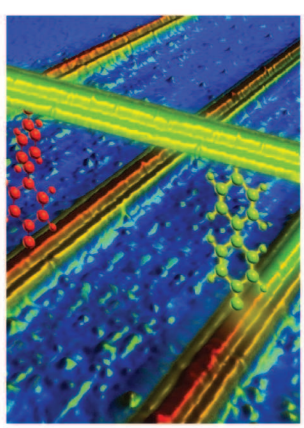
Some computer researchers believe that the technology is poised for even larger things, like general computing. It is getting more expensive and difficult to pattern, or etch, the elaborate circuitry used in microprocessors; many experts have predicted that maintaining the current rate of putting more circuits into ever smaller spaces will, sometime in the next 10 to 15 years, result in features on microchips no bigger than a few atoms, which would demand a nearly impossible level of precision in fabricating circuitry. "We are not going to be able to afford to build the Pentium 27," says Seth Goldstein of Carnegie Mellon University. "We can't afford the precision." But as it turns out, reconfigurable chips don't need that type of precision, and Goldstein and others believe the technology could offer a viable strategy for building computers that function at the nanoscale level.

"We've now discovered molecules that act just like reconfigurable logic bits," says Hewlett-Packard's Kuekes. "We are proposing fairly simple devices that can be literally grown with chemistry. Then all the complexity will be downloaded into configuration bits once the structure is made." Kuekes expects this technology will come to fruition in about ten years, just about the time silicon will peter out. "Reconfigurable logic won't just be a good idea," says Kuekes. "It will be the only way to do computing in the future." —*David Voss*

DESIGNING VERSATILITY

Opportunities in reconfigurable hardware are increasing

COMPANY	TECHNOLOGY
Altera (San Jose, CA)	Programmable chips
Chameleon Systems (San Jose, CA)	Reconfigurable logic systems for telecommunications
Hewlett-Packard (Palo Alto, CA)	Molecular electronics based on reconfigurable architecture
QuickSilver Technology (San Jose, CA)	Reconfigurable hardware for telecommunications
Virtual Computer (Reseda, CA)	Software and design tools for reconfigurable computers
Xilinx (San Jose, CA)	Field-programmable gate array logic



Hewlett-Packard will use reconfigurable logic to turn these molecular wires into devices.

THE ROBOTS ARE COMING

Morticia is quite the capable robot.

She can scramble over the outback at about 15 kilometers per hour, climb stairs, survive a 10-meter drop onto a concrete floor and even navigate underwater. Not bad for a little critter that's less than 20 centimeters high and 65 centimeters long—about the size of a small suitcase.

Created under a U.S. Department of Defense contract by an MIT spinoff company called iRobot, Morticia is a military machine with a mission. Instead of carrying bombs, she carries eyes and ears, transmitting what she sees back over a wireless link. She is also a pioneer, showing us how robots are likely to be integrated into our jobs and our lives in the coming years.

I met two of the cofounders of iRobot, Colin Angle and Helen Greiner, more than 15 years ago when they were students working on artificial cockroaches at the MIT Robotics Lab. I wasn't impressed. So when I learned a couple of years ago that Professor Rodney Brooks had formed a company with them to commercialize the cockroach technology, I pretty much wrote the whole thing off.

But when I walked through the door of iRobot's offices in Somerville, MA, earlier this year, I realized I had made a huge mistake. IRobot isn't about cockroaches—it's about creating the whole range of technologies that are necessary for building mobile, autonomous computers that perform valuable functions. This is hard stuff, requiring innovation in computer hardware, software, materials, mechanical design, wireless communication, artificial intelligence and more.

Consider Morticia—one of the first prototypes of what iRobot calls "Packbots." These are rugged machines that can be packed up in a box, thrown into the back of a van or a Humvee and hurled through the window of an office building where a crook is holed up with some hostages. The robot's most prominent features are two rotating flippers that can be used for added traction, climbing steep steps or even righting itself if it happens to fall upside down. There are two cameras in the front, optional infrared headlights and seven payload bays for extra batteries or instruments. IRobot designed and built the whole shebang, from the treads (a fundamentally new design) and the nylon wheels with the cyclone-shaped spokes (designed to absorb heavy impacts) to the flippers. You just can't buy this stuff off the shelf.

"In Los Angeles they have a hostage situation every three days," says Greiner, who is now iRobot's president. "Standard procedure is not to send in a police officer." That's because the officer might get shot or end up "amplifying" the situation.

Which is where robots come in. "If you can send in a nonthreatening robot and establish communications," Greiner maintains, many hostage situations can be defused. The robot can also look around and verify whether the hostages are still alive—or if they even exist. Packbots were also sent in to explore the rubble after the attacks on the World Trade Center last September, but, alas, they did not discover any survivors.

"It's a very good robot," says Martial Hebert, a professor at Carnegie Mellon University's Robotics Institute. As with other robots that iRobot has developed, the company plans to sell a version of the Packbot for robotics researchers around the world. Hebert has used an earlier version of the Packbot to develop advanced navigation algorithms.

If you're lucky, you will never encounter the business end of the Packbot. But within a year or so, you might find yourself looking eye to eye with another iRobot creation called the CoWorker. Designed to meander through an office building, the CoWorker looks like an oversized children's wagon with a long black neck and a cute little video camera on top. CoWorker is a mobile videoconferencing system that you can drive from room to room of your company's office in, say, San Francisco, while you're sitting in your house on the other side of the country.

Morticia is a military machine with a mission. Instead of carrying bombs, she carries eyes and ears—showing us how robots are likely to be integrated into our lives in the years to come.

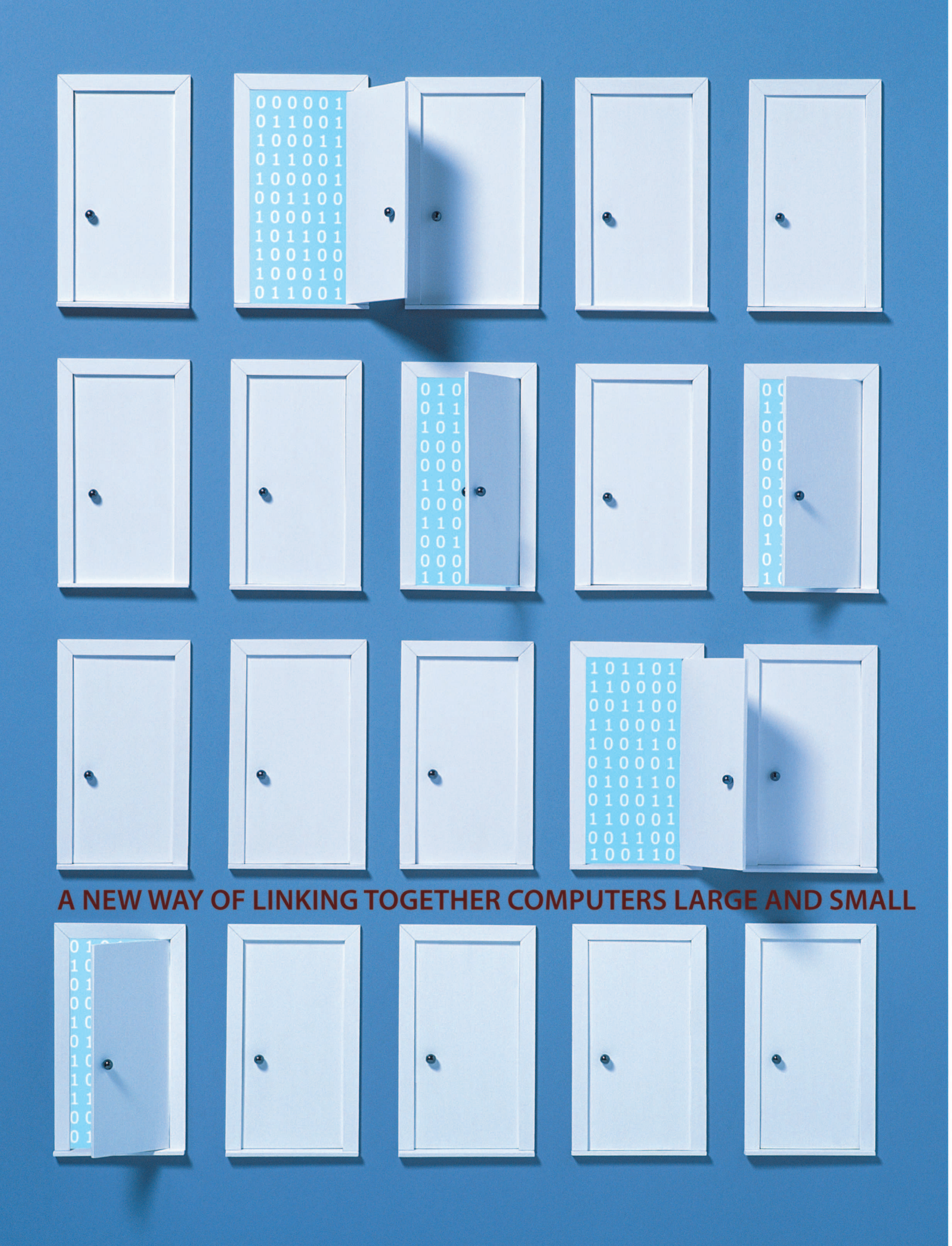
You log onto the computer's onboard Web server, view a picture of the room that the CoWorker is in, and then click your mouse where you want it to go. The robot charts a path, driving around obstacles and maneuvering through doors.

CoWorker is a big step forward from the teleconferencing systems that have been bopping around corporate America for many years. With today's systems, you need to ask your colleagues to meet you for a teleconference. With CoWorker, you drive the teleconferencing system into their offices—quite handy when the long-distance workmates won't answer your e-mails.

IRobot has also created a nine-meter-long robot that crawls down oil wells and performs measurements on the inside. And the company's consumer division has put the low-cost My Real Baby robot into the hands of more than 100,000 children since its release in November 2000.

What's happening here is clear: the real revolution in mobile computing isn't handheld computers; it is autonomous systems that can perform useful work. IRobot isn't the only company to see the potential here. ActivMedia Robotics in Peterborough, NH, for instance, sells a full line of robots for third-party developers and researchers; and don't forget Sony with its Aibo robotic dog.

This whole world of robots is amazing, and it's only going to get more so. To anyone who was just laid off from Cisco Systems, Nortel Networks or some other telecommunications company—get into robotics. This is the future. TR



Grid Computing

A NEW WAY OF LINKING TOGETHER COMPUTERS LARGE AND SMALL COULD PUT THE PLANET'S INFORMATION-PROCESSING POWER ON TAP.

BY M. MITCHELL WALDROP

ILLUSTRATION BY HOLLY LINDEM

Is Internet history about to repeat itself?

Maybe. Back in the 1980s, the National Science Foundation created the NSFnet: a communications network intended to give scientific researchers easy access to its new supercomputer centers. Very quickly, one smaller network after another linked in—and the result was the Internet as we now know it. The scientists whose needs the NSFnet originally served are barely remembered by the online masses.

Fast-forward to 2002. This summer, the National Science Foundation will begin to install the hardware for the TeraGrid, a transcontinental supercomputer that should do for computing power what the Internet did for documents. First, clusters of high-end microcomputers will be set up at four sites: the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign; the U.S. Department of Energy's Argonne National Laboratory outside Chicago; Caltech in Pasadena, CA; and the San Diego Supercomputer Center at the University of California, San Diego. Then, by early next year, those four clusters will be networked together so tightly that they will behave as a single entity.

This virtual computer will rip through problems at up to 13.6 trillion floating-point operations per second, or teraflops—eight times faster than the most powerful academic supercomputer available today. Such speed will enable scientists to tackle some of the most computationally intensive tasks on the research docket—from problems in protein folding that will form the basis for new drug designs to climate modeling to deducing the content and behavior of the cosmos from astronomical data.

But more than that, the TeraGrid will be a prime example of what has come to be known as "grid computing"—the massive integration of computer systems to offer performance unattainable by any single machine. The integration of these systems will be so transparent that users will no more notice they are on a network than motorists pay attention to which cylinder is firing at any given moment. To people logging onto the TeraGrid, the system will look like just another set of programs running on their office computers. But that look will be deceptive: what appear to be applications that reside on the local desktop machine might actually be data analysis tools running on the cluster at San Diego, or visualization software crunching bits at Argonne. The "files" TeraGrid users are working on might consist of databases scattered all over the country, containing thousands of gigabytes—a.k.a. terabytes.

Grid computing visionaries hope that this will be only the beginning—that the $53 million TeraGrid will catalyze a new era of grid computing for the masses, much as the NSFnet broke down barriers that led to the blossoming of the Internet. Just within the past year or two, dozens of such projects have been announced in Europe, Asia and the United States, with more likely to come. And the developers of grid computing are now settling on a single standard—called the Globus Toolkit—that will help grid projects under development all around the world coalesce into a worldwide network of tappable computer power.

"Completely transformational" is how Larry Smarr, director of the California Institute for Telecommunications and Information Technology, sums up grid computing. Smarr, renowned for his role in developing the communications system that evolved into the Internet's backbone, says the technology is what the Internet has been building toward for the past three decades. "In the first phase," he explains, "we got the wires up and hooked in all the computers. Then with the World Wide Web, we started hooking in all the online documents." Now, he says, with grid computing, we'll be hooking in everything else *(see "Planet Internet,"* TR *March 2002)*.

This means that users will begin to experience the Internet as a seamless computational universe. Software applications, databases, sensors, video and audio streams—all will be reborn as services that live in cyberspace, assembling and reassembling themselves on the fly to meet the tasks at hand. Once plugged into the grid, a desktop machine will draw computational horsepower from all the other computers on the grid. "What we're seeing," says Smarr, "is the emergence of a new infrastructure upon which first science, and then the whole economy, will be built."

COMPUTING AS UTILITY

That's a tall order. But it certainly describes the hope at IBM, which is the prime contractor for the TeraGrid, as well as for similar national grids in Europe. David Turek, vice president of emerging technologies for IBM's server group, compares grid computing to the familiar grid of electrical power: "To use a hair dryer, you just plug it into a wall socket," he says. "You don't have to worry about how the turbine is designed up in Niagara Falls, or the physics of power transmission." That's exactly how Turek wants people to think about computing power. "In our vision of the future, if you're a customer who occasionally needs 10 teraflops, for example, don't buy a machine that's underutilized most of the time; buy it from the grid. So grid computing will play into our vision of computing as a utility."

While companies like IBM would build the large-scale grids, Turek says that many users will want to set up grids of their own. "You might see 10 to 20 departments coming together to create a campuswide or companywide grid, each contributing some of the computer power they control," he says. In another scenario, several independent companies, such as defense contractors, might do much the same thing to create "virtual organizations"—ad hoc grids that would allow them to use one another's proprietary data and software to prepare, say, a proposal for a new military aircraft. "That's why we're not going to espouse the grid as something that can be done only with IBM technology," Turek explains. After all, he says, "if you get five companies wanting to come together on a grid, the likelihood of all five having the same servers is pretty slim."

And that, Turek adds, is the beauty of the Globus Toolkit: a set of open-source software tools that is fast emerging as the de facto standard for grid computing, in much the same way that the hypertext transfer protocol, or HTTP, is the standard for linking documents on the Web.

Indeed, the growing acceptance of Globus is largely responsible for today's wave of grid computing excitement.

"The idea is to let the network provide the basic mechanisms for moving data around, while Globus provides mechanisms for resource sharing," explains Carl Kesselman of the University of Southern California's Information Sciences Institute. Kesselman has been developing the Globus Toolkit over the past five years in collaboration with Ian Foster—a University of Chicago computer scientist who heads Argonne's distributed-systems laboratory.

The mechanisms that Globus provides are as essential to the computing grid's operation as stoplights are to city traffic. One set of Globus software tools, for example, automatically roots out where on the grid a required database or program can be found. Other tools allow one-time login, so that the user isn't constantly being asked for passwords for site after site after site. Still others divide a computational job into multiple subtasks and parcel them out among the various systems on the grid. And most important, Globus provides tools to implement security—assuring, for instance, that an outside program trying to interact with your machine is serving a legitimate purpose and hasn't been sent by some malicious hacker.

Of course, none of this is entirely new: "It's worth remembering," notes Kesselman, "that ARPAnet [the military-built ancestor of the Internet] was built in the 1960s to give users on one campus shared access to resources on a different campus." Likewise, he points out, methods for breaking computational jobs into smaller pieces for multiple machines were a perennial research topic throughout the 1970s and 1980s.

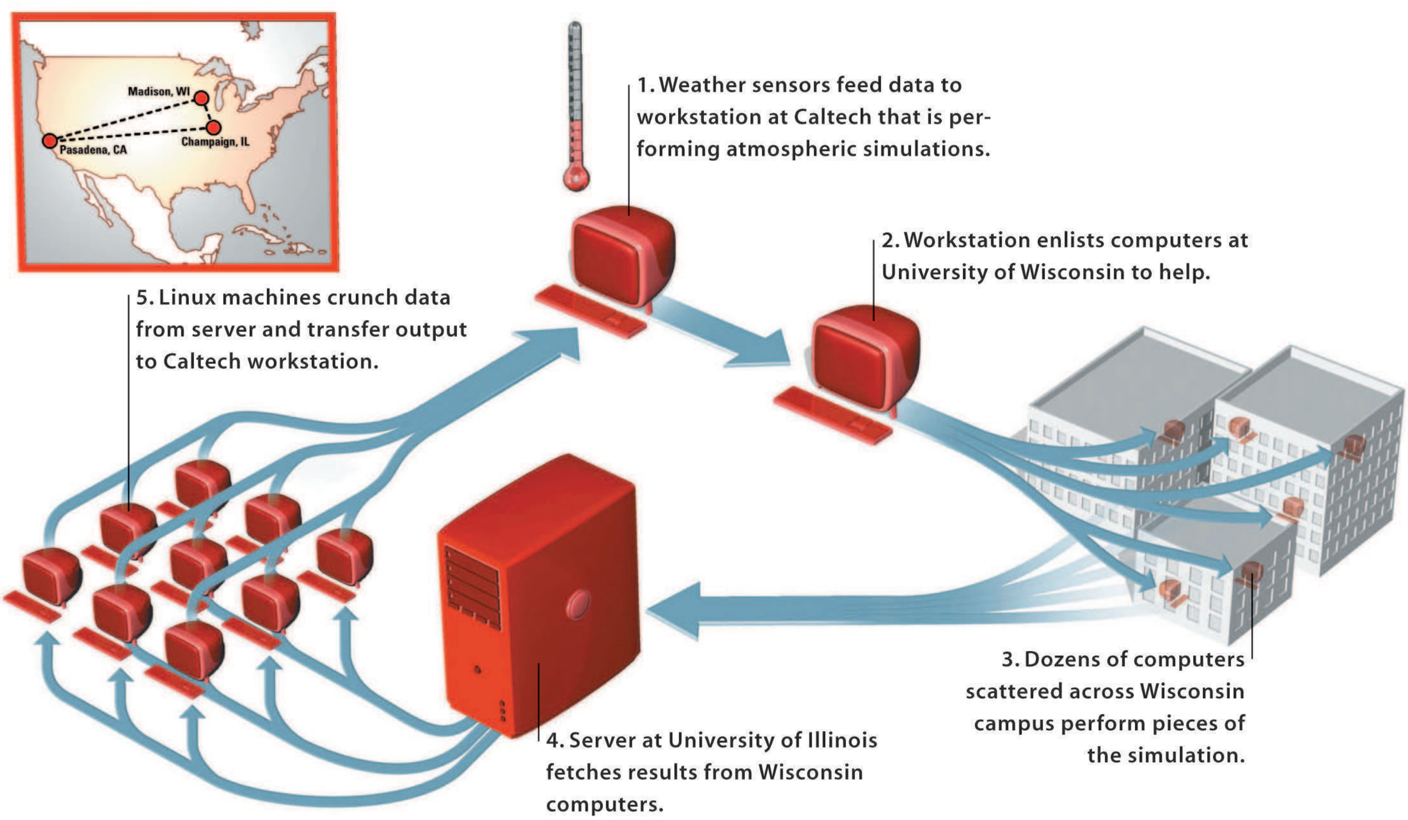
But it was only in the 1990s, Kesselman says, that the rapidly increasing power of computers and networks brought this trend, known as distributed computing, out of the laboratories. One result was a flurry of experiments in what is now known as "peer-to-peer" computing, all devoted in one way or another to harnessing the computing power and storage capacity of idle desktop machines. Among the best known of these efforts are Napster, the MP3 music file-sharing system, and SETI@home, in which radio telescope data from the search-for-extraterrestrial-intelligence project are distributed to PCs across the Internet.

At the same time, however, the high-performance-computer community began a series of less publicized but much more ambitious experiments in "metacomputing." The idea was to make many distributed computers function like one giant computer. The metamachine's keyboard and display would be sitting on someone's desktop, as usual. But its central processor might actually be a supercomputer in Illinois, say, while its graphics processor might be an immersive-virtual-reality facility in California. It worked, says Kesselman—the only problem being that experimenters had to reinvent the wheel every time. "There was still no standard software for distributed computing," he says, "no infrastructure to support it."

The technology's watershed event came in 1995, at a supercomputing conference sponsored by the Institute of Electrical and Electronics Engineers and the Association for Computing Machinery. There, 11 separate high-speed networks were briefly connected into one

Grid Work

Many computers are better than one—especially for solving tough scientific problems



SLIM FILMS

giant metacomputer in a demonstration called I-Way. Attendees thronging the San Diego Convention Center could play with an interactive model of the Chesapeake Bay ecosystem, or a high-resolution simulation of colliding spiral galaxies—some 60 applications in all. Foster, who led the team that created some of the system's underlying software, was especially impressed by I-Way's potential use in collaborative design. In one demonstration, he recalls, researchers at Argonne teamed up with those at an industrial group, Nalco Fuel Tech, to make a virtual-reality simulation for designing incinerators. "Users at different sites could fly together through the incinerator, place injectors in it at various points and jointly study the effect on its output," he recalls.

The demonstration had its intended effect. "I-Way convinced people that grid computing had great potential," says Foster. One important payoff was that in October 1996, the U.S. Defense Advanced Research Projects Agency funded Kesselman and Foster's Globus project to provide a solid foundation for grid computing. At the 1997 supercomputer conference, Foster and Kesselman demonstrated a grid with some 80 sites worldwide running Globus software—another feat that, in Foster's view, "convinced people that grid computing was worthwhile and real." At that point, moreover, Foster and Kesselman had even started to *call* it "grid computing," playing on the analogy to the electrical grid.

PHYSICS AND BEYOND

Once the concept was introduced, grid computing suddenly seemed to fill a need of scientists all over the world. In Geneva, for example, the high-energy physics lab of the European Organization for Nuclear Research (known by the acronym CERN) was already planning its next-generation particle accelerator, the Large Hadron Collider—an effort promising to generate an overwhelming amount of data. "We estimated that when the collider started running in 2006 it would produce eight to 10 petabytes of particle collision data per year," says Fabrizio Gagliardi, director of CERN's annual seminar on computing for physicists. That's *peta*bytes—millions of gigabytes.

Portions of this immense data load would have to be distributed to the institutions all over the world that participate in CERN experiments. And since the most interesting physics tends to be found in the rarest events, Gagliardi explains, scientists "would be processing every bit of that data in multiple ways"—looking for hints of the theoretically predicted but elusive Higgs boson, say, or particles that possess the mysterious quality known as supersymmetry. In short, the collider portended an enormous data management problem for which existing computer systems seemed inadequate. "We

The Growing Grid

A sampling of grid computing projects sprouting up all over the world

PROJECT	LAUNCHED	SPONSOR	MAIN PURPOSE
Access Grid www-fp.mcs.anl.gov/fl/accessgrid	1999	U.S. Department of Energy, National Science Foundation	Internet-based collaboration—including lectures and meetings—among scientists at facilities around the world
European Data Grid www.eu-datagrid.org	2001	European Union	Data analysis in high-energy physics, environmental science and bioinformatics
Grid Physics Network (GriPhyN) www.griphyn.org	2000	NSF	Data analysis for four physics projects: two particle detectors at CERN's Large Hadron Collider, the Laser Interferometer Gravitational Wave Observatory, and the Sloan Digital Sky Survey
Information Power Grid www.ipg.nasa.gov	1999	NASA	Computational support for aerospace development, planetary science and other NASA research
International Virtual DataGrid Laboratory (iVDGL) www.ivdgl.org	2002	NSF and counterparts in Europe, Australia, Japan	World's first truly global grid: will link high-performance-computer centers in Europe, Australia, Japan and the United States
Network for Earthquake Engineering and Simulation (NEESgrid) www.neesgrid.org	2001	NSF	Integrated computing environment for 20 earthquake engineering labs
TeraGrid www.teragrid.org	2002	NSF	General-purpose infrastructure for U.S. science: will link four sites at 40 gigabits per second and compute at up to 13.6 teraflops
U.K. National Grid www.grid-support.ac.uk	2001	U.K. Office of Science and Technology	Support for grid projects within Britain
Unicore www.unicore.de	2000	German Federal Ministry for Education and Research	A seamless interface to high-performance-computer centers at nine government, industry and academic labs

defined a computational architecture for what we would need," Gagliardi recalls. "Then we went shopping for a system of tools to build it—and discovered that the computer scientists had already come up with solutions."

Several solutions, actually. At the University of Virginia, computer scientist Andrew Grimshaw had been working since 1993 on an attractive and well-thought-out set of grid computing protocols known as Legion. (Legion is now being marketed by Avaki of Cambridge, MA, which Grimshaw founded.) But Globus had the advantage of being "open": in the interests of getting it adopted as widely and as rapidly as possible, Foster and Kesselman had decided to emulate the developers of the now famous Linux operating system and make the Globus source code available to any users who wanted it, so that they could study it, experiment with it and suggest improvements.

The result was that Globus became the foundation for the European DataGrid, a three-year demonstration and software development project that launched on January 1, 2001, with a commitment of 13.5 million euros (roughly $12 million) from the European Union. By the beginning of 2002, the DataGrid had deployed more than 100 computers—20 at CERN, the others at sites around the continent, according to Gagliardi, now the DataGrid's director. The project has also expanded beyond particle physics to include two other scientific disciplines that face similarly daunting data-crunching and processing challenges: earth observation and biology.

Meanwhile, grid computing has been finding an even warmer welcome among scientists in the United States—with Globus again being the choice of virtually every large project. One of the first to get going was the Grid Physics Network. Organized by Foster and University of Florida physicist Paul Avery, this effort was launched in September 2000 with $11.9 million from the National Science Foundation. It focuses on the vast amount of physical data generated by four different sources: two specialized particle detectors housed at the Large Hadron Collider; the Laser Interferometer Gravitational Wave Observatory, a Caltech-MIT collaboration that will detect gravitational waves from pulsars and the like; and the Sloan Digital Sky Survey, an international effort to map the faintest possible stars and galaxies—more than 100 million celestial bodies in all. More recent initiatives include the NSF's Network for Earthquake Engineering Simulation grid, an effort to integrate observations and computer simulations now scattered among some 20 different labs, with the goal of producing more effective designs for earthquake-resistant structures.

And now, of course, there's the TeraGrid—the "put-your-money-where-your-mouth-is grid," as Argonne's Charles Catlett calls it. "We've been talking for years," says Catlett, the project's executive director. But for the TeraGrid to achieve what it promises, the high-powered microcomputer clusters located at its four physical sites will have to be tied together by a dedicated network running at 40 gigabits per second, which will be right on the ragged edge of the state of the art. "This will show us a lot about how the software really works in a production environment," says Catlett. He's talking about the Globus software, the Internet protocols, the Linux operating system—all of it.

On the technical side, Catlett says, one of the big challenges is making sure that Globus can successfully scale up. It is critical, he notes, to make sure that Globus's services and protocols "can deal with hundreds or thousands of times more devices than they handle now." "Obviously," agrees Foster, "there is lots that still needs to be done."

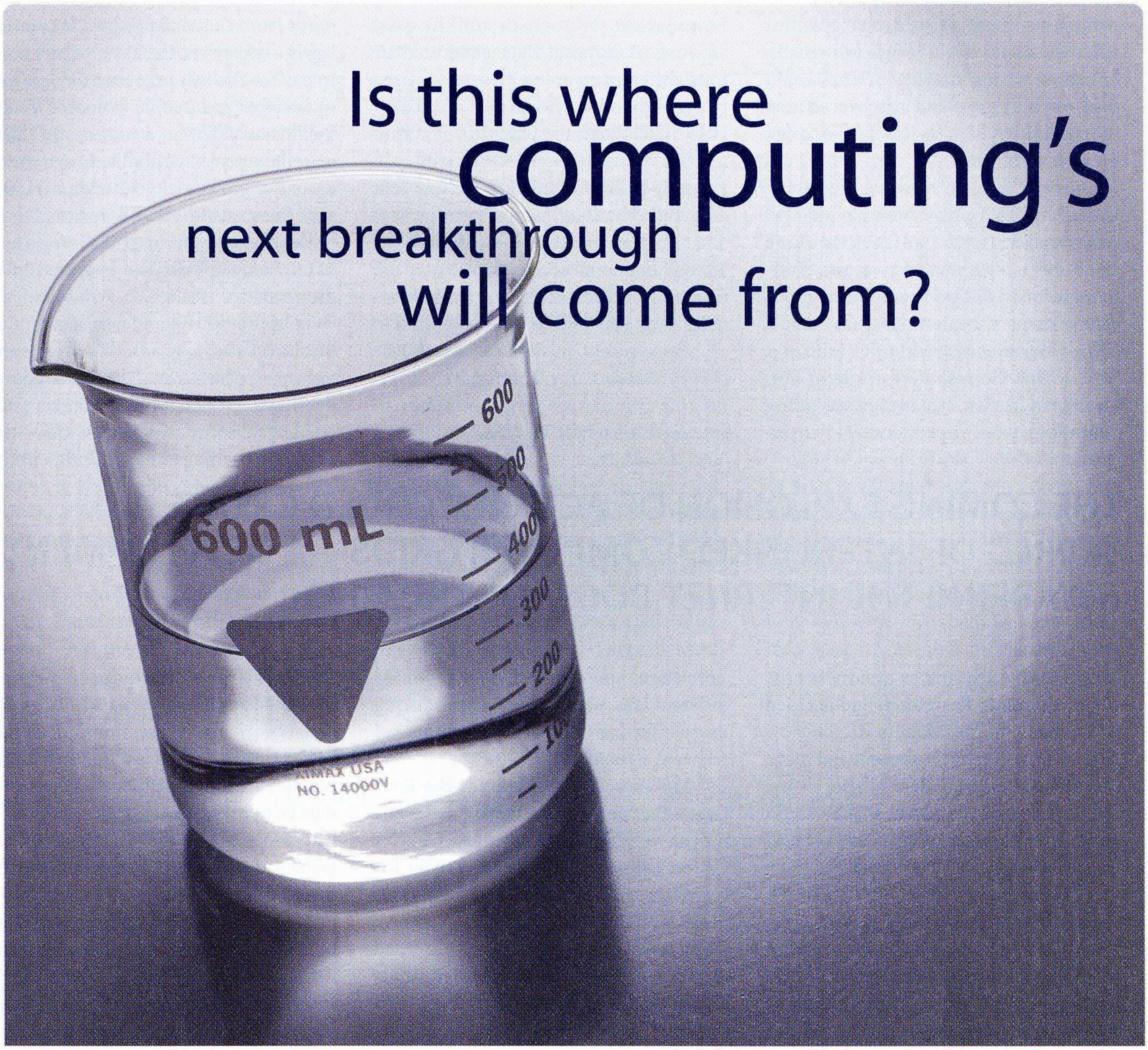
Then there's the business side. Here, grid computing runs into the same question that sank so many of the over-optimistic dot coms: how will money be made from this technology? "If computing is a utility," Foster says, "who's going to pay for the infrastructure? What kind of services are people prepared to pay for?" In particular, where is the killer app, the must-have application that will drive the growth of grid computing the way the spreadsheet did personal computing? Most current grid projects have barely moved past the if-we-build-it-they-will-come stage.

On the other hand, says Foster, "we do have some ideas." One notable example is the Access Grid, an Argonne-developed system—based, like so much else in grid computing, on Globus—that supports large-scale, multisite meetings over the Internet, as well as lectures and collaborative work sessions. It already links more than 80 academic and industry sites around the globe. Furthermore, says Foster, as more and more big scientific projects like the TeraGrid and the DataGrid come on line, there's every reason to think that they will serve as laboratories for new grid applications that will then make their way into the commercial world, with huge impact. After all, the Internet's killer app, the World Wide Web, didn't come out of a corporate lab. It came out of CERN.

THE COMING EXPLOSION OF ACTIVITY COULD CREATE A WORLD OF INTERLINKED COMPUTER GRIDS—A DEVELOPMENT DWARFING THE INTERNET BOOM OF THE 1990s.

GRID UNLOCKED

While the Web may be a tough act to follow, grid computing advocates have been paving the way for the technology's hoped-for commercialization by focusing on such nitty-gritty issues as standards-setting. "Remember how much we've gained from the fact that every computer runs the Internet Protocol," says Foster. To achieve the same universality for grid computing, the U.S. grid community has merged with those of Europe and Asia to form the Global Grid Forum—an organization patterned after the Internet's standards-setting body, the Internet Engineering Task Force. The forum's goal is to make sure that Globus, Legion and any other grid protocols can


Is this where
computing's
next breakthrough
will come from?
600 mL
600
400
300
200
NO. 14000V

interoperate seamlessly. "If every computer uses standard methods for managing authentication, authorization, describing resource capabilities and negotiating access for resources," says Foster, "that's a big win."

The grid pioneers are likewise building alliances with their counterparts in commercial peer-to-peer computing. In practice, however, peer-to-peer efforts appear to be most effective for problems that can easily be broken into myriad small, independent pieces—a category that does *not* usually include, say, the complex physics simulations and virtual-immersion applications where grid computing really shines. Nonetheless, Foster says, the potential for synergy is clear. That's why the Globus protocols have already been integrated into such industrial-strength peer-to-peer systems as the Condor protocols developed at the University of Wisconsin-Madison and the Entropia platform from Entropia of San Diego, both of which are designed to capture the unused capacity of an organization's networked workstations.

The payoff for such efforts is that the computer industry now seems to be taking grid computing very seriously indeed—with the most notable example being IBM. Last August, at the same time it won the contract to build national grids in the United Kingdom and the Netherlands, as well as TeraGrid in the United States, Big Blue announced that it would "grid-enable" many of its server systems. This initiative, which would mean that servers in many institutions and organizations could be plugged into grid networks quickly and easily, was said to be as big or bigger than IBM's commitment to Linux, which already stood at roughly $1 billion. (Indeed, IBM had already used Globus to link its own R&D labs in the United States, Israel, Switzerland and Japan.)

Yet IBM is hardly alone. Last November, eight other computer makers—Compaq, Cray, Silicon Graphics, Sun Microsystems and Veridian in the United States, together with Fujitsu, Hitachi and NEC in Japan—announced that they would implement the Globus Toolkit on their machines as a standard platform for grid computing. Then early this year, Microsoft completed a contract with Argonne to translate the existing Globus Toolkit to Windows XP, according to Todd Needham, manager of the software giant's University Research Programs group.

If nothing else, Microsoft's move should hasten the day when home and office computers will be able to join the grid by the millions, just by plugging in. But perhaps just as significantly, it also symbolizes the fast-developing alliance between grid computing and "Web services," a similar technology that has emerged independently over the past few years and has been embraced in slightly different forms by Microsoft, IBM and Sun, among others. Like grid computing, the Web services idea revolves around future software applications that are created on the fly out of programs and data that live on the Internet, not the user's machine. The main difference between this idea and grid computing is that Web services software tends to be much more closely tied to the World Wide Web protocols, as well as to Web-based standards such as XML.

Once again, however, as Microsoft and IBM's embrace of Globus suggests, the potential for synergy is obvious. In January, Foster, Kesselman, IBM's Jeffrey Nick and Argonne's Steven Tuecke proposed an Open Grid Services Architecture that would integrate the two approaches, and announced that this framework would be implemented as version 3.0 of the Globus Toolkit. IBM, Microsoft, Platform Computing, Entropia and Avaki announced their support of the new architecture, with other companies to follow.

And in the future? History is indeed about to repeat itself, declares grid computing advocate Smarr—except that the explosion of grid activity may very well dwarf even the Internet boom of the 1990s. In the future envisioned by Smarr, grids of every size will be interlinked. The "supernodes," like TeraGrid, will be networked clusters of supercomputers serving users on a national or international scale. The more numerous mid-sized nodes will use software such as Entropia to harness the power of multiple desktop and laptop PCs. If the TeraGrid and other supernodes are like central electric power stations, Smarr explains, these smaller nodes will be like solar energy collectors that capture a diffuse yet enormous resource.

Still more numerous will be the millions of individual nodes: personal machines that users plug into the grid to tap its power as needed. If, say, the members of a citizen's group were worried about a proposed development project, they could use the grid to run the same simulations that the developers and government officials involved used. That way, they could easily see the effect of the development on everything from ground water to traffic patterns to employment. By using grid-based tele-immersion technologies, the citizens could even walk through the simulated project and get a realistic sense of what it would feel like to *be* there.

And thanks to the wireless revolution, "micronodes" will be everywhere. "Because of the miniaturization of components," says Smarr, "we'll have billions of endpoints that are sensors, actuators and embedded processors. They'll be in everything, monitoring stress in bridges, monitoring the environment—ultimately, they'll even be in our bodies, monitoring our hearts."

And that, he emphasizes, is why we have to lay a solid foundation for the grid now, building in security and all the rest from the start. "We can't do it as an afterthought," he says. "The planet is assembling the grid infrastructure that it will live on for the rest of 21st century." TR

GRID USERS WILL EXPERIENCE THE NET AS A SEAMLESS COMPUTATIONAL UNIVERSE. SOFTWARE, DATABASES AND SENSORS WILL BE REBORN AS SERVICES ASSEMBLED ON THE FLY.

To join an online discussion of this article, visit www.technologyreview.com/forums/grid

should the government make vaccines?

VACCINES AGAINST DISEASES FROM ANTHRAX TO INFLUENZA ARE IN DANGEROUSLY SHORT SUPPLY, AND GOVERNMENT AND INDUSTRY EXPERTS ARE SQUARING OFF OVER A CONTROVERSIAL PROPOSAL TO BOLSTER THEIR PRODUCTION. AT STAKE, SOME SAY, IS THE VERY HEALTH OF THE NATION.

By Jon Cohen and Eliot Marshall | Illustrations by Alex Williamson

on november 27, with the united states still reeling

from the attacks on the World Trade Center and the series of anthrax-spiked letters, legislators at a hearing on Capitol Hill got more shocking news. They learned that the country was ill prepared to deal with future attacks from microbes—and not just the kind released by terrorists. One expert after another testified to the Senate's Committee on Health, Education, Labor and Pensions that in the past year the country had suffered various shortages of the vaccines critical to fighting infectious diseases. The witnesses' warnings went beyond the threats of anthrax and smallpox, describing a chronic lack of vaccines for common influenza, which claims 20,000 American lives a year, and the childhood menaces tetanus, pertussis, diphtheria and pneumococcal disease.

These problems are not new. But they took on an unprecedented sense of urgency after September 11, when it became apparent that the country had paltry supplies of smallpox and anthrax vaccines on hand—and no vaccines whatsoever for many other potential bioweapons. What's more, it was also obvious that the United States lacked the manufacturing infrastructure to quickly remedy the problem, or deal with a widespread epidemic of anything from smallpox to the flu. "These shortages call into serious question our ability to continue to meet the public-health needs of our citizens," said Senator Jack Reed, a democrat from Rhode Island, at the opening of the hearing.

The situation is largely a result of the failure of market forces to encourage vaccine production, which is a risky and far from lucrative business. Only four large pharmaceutical companies in the world still make vaccines. And while the four manufacturers compete on some vaccines, and several biotechnology companies are attempting to fill in gaps, the general lack of competition means that shortages occur routinely. Seemingly minor glitches can interrupt supplies: a business decision, a regulatory ruling or trouble in a laboratory or manufacturing plant.

Fear of a looming health crisis is, for the first time, prompting scientists, industry leaders and policymakers to take a sweeping look at the nation's vaccine needs, both exotic and routine. One bold solution: a proposal to supplement private vaccine production with a federal initiative. This scheme calls for the U.S. government to establish a National Vaccine Authority to oversee research, development and distribution of vaccines that are too risky or too unprofitable for industry to make. A central component would be a government-owned, contractor-operated vaccine-manufacturing plant.

It is a controversial idea that has been proposed before, only to be overwhelmed by industry objections. But the confluence of September 11 and a recent, acute vaccine supply problem has changed the tenor of this long-standing debate. "The anthrax terrorism event clearly exposed the weaknesses we have in the research, development and production of vaccines that are important for fighting terrorism, and at the same time dramatized that we have significant problems with vaccines that are important for the civilian sectors," says Kenneth Shine, president of the Institute of Medicine, the health-care-research arm of the National Academy of Sciences.

ORPHANS

The Institute of Medicine first floated the National Vaccine Authority idea nearly 10 years ago and is still its most outspoken advocate. Strong support also comes from the Gilmore Commission, an advisory panel established by Congress in 1998 to suggest better responses to terrorism, and an independent panel that in 2000 evaluated the military's fractured vaccine production system. The bottom line in each analysis is the bottom line: the market for vaccines is too weak for private investments to sustain it. "Sooner or later we have to come to grips with the fact," says Shine.

Take anthrax. Until recently, there was hardly any market for this vaccine—and no commercial producer to make it. For decades, the Pentagon contracted with a laboratory owned by the state of Michigan to manufacture the vaccine, but that lab repeatedly ran afoul of U.S. Food and Drug Administration regulations. In 1998, the state finally sold the lab to a private outfit, BioPort, a new company backed by investors who had deep ties to the U.S. and British militaries. But the U.S. Department of Defense's stockpile of vaccine began to dwindle as BioPort renovated the aging facilities. When the anthrax attacks occurred in October 2001, the plant still had not received final regulatory approval, and the Defense Department had so little vaccine on hand that it had suspended its own mandatory anthrax vaccination of all troops. Though the FDA has since given BioPort the green light, anthrax vaccine remains a scarce commodity.

September 11 also brought smallpox into sharp focus. The government's stockpile of the original smallpox vaccine is nowhere near enough to protect the entire U.S. population, and no big pharmaceutical company has manufactured it since 1982. And though the Departments of Defense and Health and Human Services have each contracted with a different company to make a new smallpox vaccine, it will be several years before they see any results. The Department of Defense has also instructed its contractor to make vaccines against several other potential bioweapons, but that process is so cumbersome that it could easily take a decade before the first of these can be proved safe and effective.

And the problems don't stop with rarely used bioweapon vaccines. American children receive a battery of vaccines to combat 11 diseases, many of which have thus become uncommon. But in the past year, shortages have occurred with four of these vaccines for a wide variety of reasons *(see "Vaccine Shortfalls," p. 43)*. It is too early to assess the extent of the shortages, but many witnesses at the November 27 hearing, as well as senators themselves, made it clear that they are real.

Democratic senator Jeff Bingaman reported that in his home state of New Mexico there is a shortage of tetanus boosters for 11- to 15-year-olds. An epidemiologist representing the Association of State and Territorial Health Officials testified that because of a vaccine shortage, Tennessee could not enforce its requirement that children in day-care facilities be immunized against pneumococcal disease. He added that a diphtheria vaccine shortage "has plagued all states," and that a shortage of pertussis vaccine forced Colorado to suspend a requirement that children receive fourth and fifth booster doses. With influenza vaccines—which face delivery problems every year, since they must annually be made anew to combat the latest flu strains—unusually severe delays in 2001 have left many elderly people without protection.

In some ways, the problem is the fault of the lawmakers themselves, caused by legislative fine print. Regulators have long recognized that pharmaceutical manufacturers lack the financial incentive to make treatments for diseases that affect only a small fraction of the population. Congress attempted to rectify this in 1983 by passing the Orphan Drug Act, which subsidizes research and development for "orphan" medicines, defined as drugs that treat diseases affecting fewer than 200,000 people in the United States, or drugs whose U.S. sales aren't expected to cover the cost of development. But vaccines aren't covered by this law, and there is no comparable "orphan vaccine" act. This means that without the economic incentives of a large potential market, industry will step up to the plate only when the government offers contracts to make specific vaccines.

MISSION VACCINE

The Institute of Medicine's Shine thinks there is a reasonable way out of this bind. His idea is based on a plan he and others introduced nine years ago. In 1993, the Institute of Medicine issued a report that spelled out how the United States could best support a broad effort to increase the number of children receiving basic immunization. The report advocated creating a National Vaccine Authority that would "advance the development, production and procurement of new and improved vaccines of limited commercial potential but of global public-health need." Despite making a big media splash for a time, the proposal never made much headway.

Since September 11, the Institute of Medicine has aggressively shopped the idea around once again. The new version calls for a total overhaul of the vaccine enterprise, and a National Vaccine Authority that would meet both civilian and military needs. The authority would oversee a government-owned manufacturing plant that would not only make vaccines for rare diseases and bioweapons but also fill in the supply gaps for more common diseases. In addition to manufacturing vaccines, Shine says, the authority would sponsor research into new vaccine ideas that hold little commercial interest. Combining three vaccines into one product, for example, makes the vaccines easier to administer—but offers no obvious benefit to manufacturers, particularly if the three vaccines are made by different companies.

"It's not about replacing the private sector," says Shine. "It's based on the notion that there is a spectrum of vaccine needs that cannot and will not be met by the private sector." Shine still believes, however, that industry has a role to play. He envisions the proposed manufacturing system as a private-public partnership, not a huge government bureaucracy. During World War II, just such a partnership, led by a U.S. Department of Agriculture lab, had tremendous success in quickly producing massive amounts of penicillin for Allied troops and, by the war's end, the public at large.

Shine's conclusions are remarkably similar to those reached independently by a panel that reviewed the military's own vaccine acquisition program. The military's reliance on a network of contracts with private manufacturers "is insufficient and will fail," the panel wrote in its December 2000 report. The panel instead recommended that the government build its own vaccine production plant and hire a contractor to operate it, calculating that a $3.2 billion research-and-development program

THE PROPOSAL FOR A NATIONAL VACCINE AUTHORITY IS "BASED ON THE NOTION THAT THERE IS A SPECTRUM OF VACCINE NEEDS THAT CANNOT AND WILL NOT BE MET BY THE PRIVATE SECTOR," SAYS THE INSTITUTE OF MEDICINE'S KENNETH SHINE.

IN THE WEEKS JUST AFTER THE OCTOBER ANTHRAX MAIL ATTACKS, WHEN CONCERN ABOUT VACCINE SHORTAGES WAS GREATEST, THE DRUG COMPANIES ISSUED REASSURANCES THAT THEY WERE TAKING THE SUPPLY PROBLEM SERIOUSLY.

could reliably produce eight vaccines. The U.S. surgeon general subsequently endorsed the idea and suggested that it could benefit civilians, too.

In fact, for several decades, the Department of Defense actually had such a facility—a vaccine plant in Swiftwater, PA. While it was owned and operated by the La Jolla, CA-based Salk Institute for Biological Studies, the plant was dedicated exclusively to manufacturing vaccines to defend army troops against possible biological weapons. "It was a well-organized laboratory with good staff completely at the discretion of the army," recalls Alexis Shelokov, who headed the facility from 1981 to 1991. The Swiftwater-made vaccines, says Shelokov, cost the government "practically nothing per dose." And Swiftwater's managers steadily upgraded the facilities to keep pace with the state of the art.

In the mid-1990s, in a move that dumbfounded many observers, the Department of Defense decided to dump the Swiftwater plant in favor of its current contract-based vaccine program. But now the military's skyrocketing demand for anthrax and smallpox vaccines is making the program's shortcomings all the more apparent—and the recommendations of both the military review panel and the Institute of Medicine for a government-owned vaccine plant are receiving new attention.

The Institute of Medicine did not suggest which agency should ultimately run a national vaccine program but hinted that a collaboration between the Defense Department and Health and Human Services might work. Retired U.S. Army major general Philip Russell, a vaccine expert recently recruited by the Bush administration to work on biological defense, has a different idea altogether. "What it really needs," Russell said, "is a NASA-like organization that is independent and meets the needs of both agencies and is not encumbered by either bureaucracy, but can just accomplish its mission."

BAD REACTION

It's a mission, however, that will never get off the ground if the pharmaceutical industry has anything to say about it. Big pharmaceutical companies have also expressed concern about vaccine supplies but claim that they are already working on a solution. Though the industry's strategy has not been spelled out in detail, executives at Merck and other companies know what they don't want: the investment of tax dollars in a big federal project. That, they argue, would be a disaster.

In the weeks just after the October anthrax mail attacks, when concern about shortages was greatest, the drug companies issued reassurances that they were taking the supply problem seriously. The Washington, DC, lobby that represents drug firms—the Pharmaceutical Research and Manufacturers of America—recruited Michael Friedman, a former acting commissioner of the FDA, to manage an emergency working group made up of representatives from a score of drug companies. Friedman argues it would be a mistake to build a taxpayer-owned facility. The assumption that government must take charge because vaccines are inherently unprofitable is inaccurate, he says, contending that it was not just a lack of profits but national complacency about infectious diseases that led to a dearth of vaccines. All that has changed, Friedman says: "Now that we are facing a real bioterrorist threat… public and private resources will be mobilized."

Pharmaceutical executives are wary of anything that smacks of increased federal involvement in their business. Adel Mahmoud, president of Merck Vaccines, the world's second-largest maker of vaccines, says the National Vaccine Authority plan is far too ambitious and would surely fail to meet its goals. He thinks many people underestimate just how difficult it is to produce vaccines on a mass scale. Moreover, he points to an eight-year-old federal vaccine purchase program that helps states immunize children—a program he says is already doing economic harm. Federal officials bargain hard to get a low price in these massive purchase deals, Mahmoud says. They "twist my arm to the point where [they create] a price cap." And price caps discourage production. "In an open-market society, let the field develop according to the forces that will shape it," Mahmoud says. "The more you regulate it, the more you undermine it."

Large firms like Merck are the main players in vaccine manufacturing today, but biotech companies are making innovations that will be important for the future. And among the smaller companies, attitudes about the proposed vaccine authority vary widely. Some executives are strongly opposed—like William Haseltine, CEO of Human Genome Sciences of Rockville, MD. Haseltine says, "You don't ask DOD to build fighter planes; why should it make vaccines?" He believes the government should invest not in production facilities but in the basic science of infectious diseases and coax academics into long-term partnerships with industry. "We need to rebuild and provide funding; the new scientists will come," Haseltine says.

Industry skeptics like Haseltine are easy to find, but Thomas Monath, vice president for research at Cambridge, MA-based Acambis, says, "I am one of the rare people in industry who thinks it would be a good idea" to build a federal vaccine production facility. Monath, who began his vaccine development career on the army's staff at Ft. Detrick, continues to advise military and civilian officials.

Another supporter of the idea is Franklin Top, executive vice president of MedImmune, a biotechnology firm in Gaithersburg, MD. Top thinks contracting out to a smattering of private firms might cost more money—and take longer—than concentrating the work in a facility owned by the government and directed by outside experts. "Once the big contracts are in place, you're stuck with them," he says. "These behemoths have a life of their own."

DEAF EARS

The arguments for and against a National Vaccine Authority have been refined during a decade of debate over the issue. In many ways, however, the shock of the terrorist attacks changed the climate surrounding the vaccine debate in Washington, as well as in industry. As General Russell said right before he was recruited into the Bush administration, "People began to behave more in a manner of 'How do we solve a national problem?' rather than 'How do I defend my bureaucratic ass?'"

But so far, neither the administration nor Congress has shown much enthusiasm for a National Vaccine Authority. Congress did decide to pour hundreds of millions of biodefense research dollars into the National Institutes of Health this year. But it did not draw up a master plan for translating research into vaccines—and it did nothing to address the shortages of vaccines for childhood and other common diseases. For now, the government is relying on the standard approach: giving out research grants and contracts and hoping that industry will rise to the challenge.

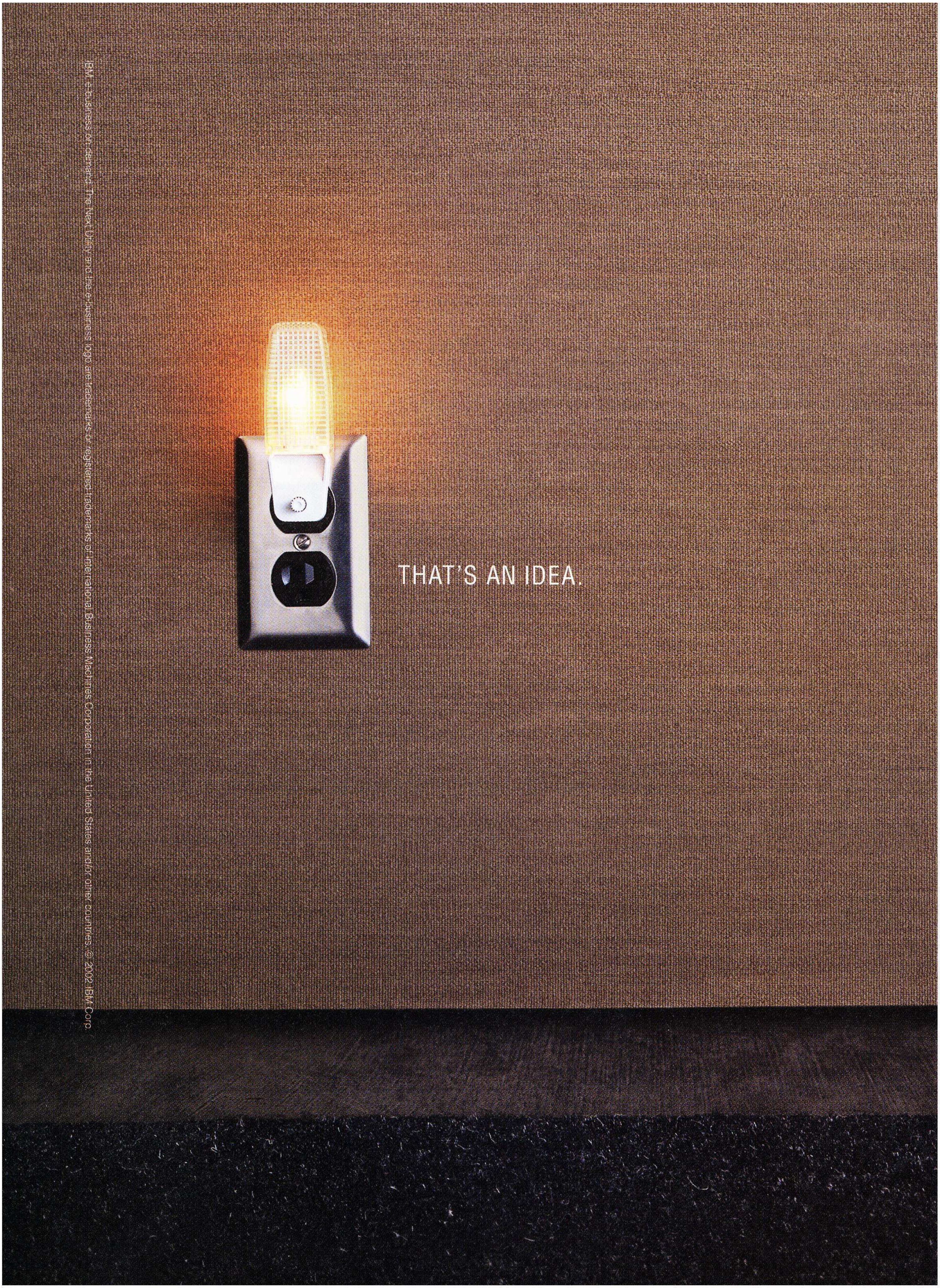
During the November 27 Senate hearing on vaccine shortages, Rhode Island senator Reed was obviously disturbed by the landscape of troubles that the experts described. This, Reed said, is "an amazing situation." It is—one that will require an amazing solution. Perhaps that solution lies in a National Vaccine Authority, and perhaps not; it's hard to see how those feuding over the question will reach a truce. If they can't, and if the status quo is preserved, no less than the health of the nation will be the casualty. TR

To join an online discussion of this article, visit
www.technologyreview.com/forums/vaccines

Vaccine Shortfalls

For a variety of reasons, supplies are low for a number of the vaccines most needed in the United States

VACCINE	SYMPTOMS	CAUSES
Diphtheria and tetanus	Nationwide shortage causing delays of routine booster shots for adolescents and adults	One of two manufacturers left market
Diphtheria, tetanus and pertussis	Nationwide shortage causing fourth and fifth boosters to be deferred	Two of four manufacturers left market; removal of chemical preservative forces change from multidose to single-dose vials, which cuts yield
Influenza	Only 50 million doses available in October 2001, as compared to 75 million in October 1999	One of four manufacturers left market; one manufacturer not in compliance with U.S. Food and Drug Administration's manufacturing procedures
Measles, mumps, rubella	Delays of six weeks in delivery	One manufacturer, production problems
Pneumococcal	34 states face shortages, causing vaccination in children older than two to be deferred	Single manufacturer of new product
Varicella	Delays of six weeks in delivery	One manufacturer, production problems
Anthrax	U.S. Department of Defense suspends mandatory military vaccination; none routinely available for civilians	One manufacturer, FDA violations
Smallpox	U.S. stockpile only enough to vaccinate five percent of population	Original vaccine out of production; manufacturers of new vaccine yet to deliver product


THAT'S AN IDEA.
IBM, e-business on demand, The Next Utility and the e-business logo are trademarks or registered trademarks of International Business Machines Corporation in the United States and/or other countries. © 2002 IBM Corp.

The Invention Factory

BY EVAN I. SCHWARTZ

PHOTOGRAPHS BY TIMOTHY ARCHIBALD

Nathan Myhrvold, once Microsoft's designated visionary, is out on his own—aiming to assemble a dream team of the world's best inventors to create great new stuff.

Invention under the microscope: Myhrvold, who collects antique gadgets, wants to test new ways of stimulating inventors' genius.

Over lunch in his suburban Seattle office, Nathan Myhrvold says he's looking forward to an afternoon meeting with a group of nuclear-fusion experts. "It's a real bitch," he remarks of the problem scientists have had controlling hydrogen reactions and achieving the ultimate dream of cheap, safe, renewable energy. Such thorny technological conundrums fascinate the bearded, cherubic veteran of Microsoft's inner sanctum. Like dozens of other domains, he says, fusion is ripe for a revolution. "There needs to be a big new idea," Myhrvold muses.

Big ideas are what Myhrvold is all about. Currently the president of a freewheeling outfit called Intellectual Ventures—an umbrella company he formed two years ago to pursue his diverse interests—Myhrvold is fascinated by the very process of thinking up groundbreaking concepts. "I'm interested in how amazing new ideas are generated, and what it takes to bootstrap those ideas and grow them afterwards," he says. To that end, Myhrvold recently disclosed to *Technology Review*, Intellectual Ventures has been working on a secret project for the better part of two years. The ambitious undertaking, which he is tentatively calling the Invention Factory, would bring together perhaps dozens of established and promising inventors to craft both significant innovations and methods to broaden their impact on the market. In fact, Myhrvold says he has been meeting with every significant inventor he can find to attempt to rope people into his still-evolving plan. "I've tried to speak to all of the world's great inventors—but only the living ones," he smirks. "I'm particularly interested in the ones who have made big scores."

Myhrvold's vast personal wealth, estimated in the hundreds of millions of dollars, along with his track record as the founder of Microsoft Research—"the man Bill Gates put in charge of the future," as the *New Yorker* put it in 1997—means that any big idea he puts into action is bound to create a stir in the technology world, especially now that he's not constrained by a specific corporate agenda. Unlike a traditional corporate research lab, Myhrvold's new outfit wouldn't be tied to any particular product or market but would be free to investigate any industry or field in need of new inventions. "We want to create new stuff, either evolutionary or revolutionary stuff," he says.

Either working in Myhrvold's offices in Bellevue, WA, or remaining in their own laboratories, members of this inventors' collective would collaborate on patentable ideas in areas ranging from biotechnology to distributed computing, energy, military innovations and even business processes. The venture would be a for-profit business, with revenue coming from the licensing of patents that its inventors produced, and its business model would be built around an unusual way of compensating those who create valuable intellectual capital: individual inventors would split license fees and royalties with the company. Thus inventors would profit in direct proportion to the success of their inventions—although many would also be paid a salary.

"Our whole notion is that invention is important enough to say, Let's invent, and create the context for inventing, and get inventive people to do it."

Why challenge a system of large-scale corporate research that has worked fairly well for decades? Corporate labs "often produce inventions, but that's not their job," says Edward Jung, Myhrvold's partner at Intellectual Ventures and Microsoft's former chief software architect (a position now held by none other than Bill Gates). "Even though it creates a huge amount of value, invention is usually just a by-product of industrial research. In many ways, it's been given short shrift. Our whole notion is that invention is important enough to say, Let's invent, and create the context for inventing, and get inventive people to do it." Invention Factory members, Jung says, will jump across problem domains in order to spur serendipitous discovery, whereas researchers at labs run by companies such as Microsoft, IBM or Lucent Technologies tend to work in well-defined areas, often spending their entire careers in one narrow field.

To attract some of the world's top inventors to participate, Myhrvold and Jung not only want to compensate them well but also aim to tap into the sheer joy that inventive people draw from their work—an emotion that they believe has largely been missing in corporate labs for a long time. As Myhrvold puts it, "Invention is so exhilarating that most true inventors would do it for free."

FOURTH ERA OF INVENTION

If anyone can bring the Invention Factory to life, it ought to be Myhrvold. His training and experience extend to so many fields that he is as comfortable brainstorming with software designers or nuclear scientists as he is kibitzing with French chefs or science fiction authors. Talking about obstacles in just about any area of technology gets him energized; the pace of his speech quickens and he breaks out into roiling laughter at the slightest provocation.

Myhrvold, 42, joined Microsoft in 1986 after undergraduate and graduate training in mathematics, economics and physics, not to mention postdoctoral work under Stephen Hawking at the University of Cambridge in England and a brief tenure as the president of his own software startup, which was acquired by Microsoft. His subsequent appointment as Microsoft's chief technology officer gave him license to explore dozens of high-tech domains, from interactive television to speech recognition, and in 1991 he convinced the company to start Microsoft Research, which has grown into one of the largest corporate research labs launched in the past half-century.

Yet even the ability to pursue almost any software-related research project wasn't enough to absorb all of Myhrvold's wide-ranging attention. During his final years at Microsoft he began delving into paleontology and other exotic fields, even taking leaves to go digging for dinosaur bones. In fact, the fossil of an ancient reptile now hangs on his office wall, while the Intellectual Ventures lobby is adorned with the head of a dinosaur

Room for growth: Edward Jung, former chief software architect at Microsoft, says most corporate labs give inventors short shrift.

model used in one of the *Jurassic Park* films and a small museum's worth of obsolete gadgets, like a solar-powered telegraph and a giant slide rule for high-precision calculations.

After leaving Microsoft in 2000 with an estimated $650 million in company stock, Myhrvold had the freedom to think seriously about the conditions that foster invention. He and Jung are founding the Invention Factory on the strength of his theory that the American economy is entering its "fourth stage" of innovation, a time when the long-dominant corporate labs are losing their edge and the truly world-changing inventions may once again come from inventors working alone or in small groups, as they did in the 19th century.

The first stage of innovation, Myhrvold says, was a golden era sparked by 1830s patent law changes that made the process of reviewing and granting patents much more rigorous. This reduced the likelihood that more than one patent would be granted on the same basic idea, making each patent much more valuable, and encouraging a parade of great lone inventors from Samuel Morse and George Westinghouse to Alexander Graham Bell and Thomas Edison. The parade continued into the early part of the 20th century with inventors like the Wright brothers, Bakelite creator Leo Baekeland, Polaroid founder Edwin H. Land and television pioneer Philo T. Farnsworth.

But by that time Myhrvold's second stage, the era of corporate-controlled innovation, was already under way. At the turn of the century, companies such as General Electric, DuPont and AT&T began hiring scientists and engineers by the hundreds in an attempt to come up with more breakthroughs before outsiders could disrupt their monopolies. These companies' labs kept the rights to new inventions to themselves, blanketed their fields with filings and overpowered the lone inventors with legal assaults. By the 1920s, corporations moved to gain a majority share of U.S. patents for the first time *(see "Lone Inventors Lag Behind," this page)*.

This system ultimately produced the transistor and launched the microelectronics and computing industries, but by the 1970s, Myhrvold notes, economic pressures were putting the squeeze on corporate research-and-development budgets. Many corporate labs dating from the early or mid-20th century have now been struggling for years. Often, maintains Myhrvold, the surviving corporate research labs became demoralizing work environments, places where "potentially great inventors are treated as mid-level engineers."

Entrepreneurs seized the mantle from the corporate labs beginning in the late 1970s, when the PC era commenced. This transformation, Myhrvold's third stage of innovation, gave rise to the Silicon Valley model, in which leading university researchers, students and corporate rebels obtain massive infusions of private venture capital to fund what Myhrvold describes as largely development work and marketing efforts. But with the bursting of the dot-com bubble in the spring of 2000, this model too has suffered a decline. "The Silicon Valley model has been fantastic," Myhrvold says, "but it's been stretched to the limit. We've had a lot of talented people with a lot of money pursuing dumb ideas."

Brainstorming for a better model, Myhrvold is setting out to launch the fourth stage of innovation. This new era, he says, has two distinct characteristics never seen before. First, there is still plenty of financing available for truly great ideas. Second, individual inventors are armed with an unprecedented array of information tools—such as powerful computers that can create 3-D simulations of new products and test their functions—that weren't available even at the corporate labs or the startups of the past. As a result, Myhrvold believes, independent inventors reminiscent of the heroes of the first stage can rise to ascendancy once again. Yet if these inventors focus purely on creation, they'll need assistance and an infrastructure to support them—which is what the Invention Factory is all about. Says Myhrvold, "We think the time is ripe for organized lone inventing to come back."

MAKING GOOD INVENTORS GREAT

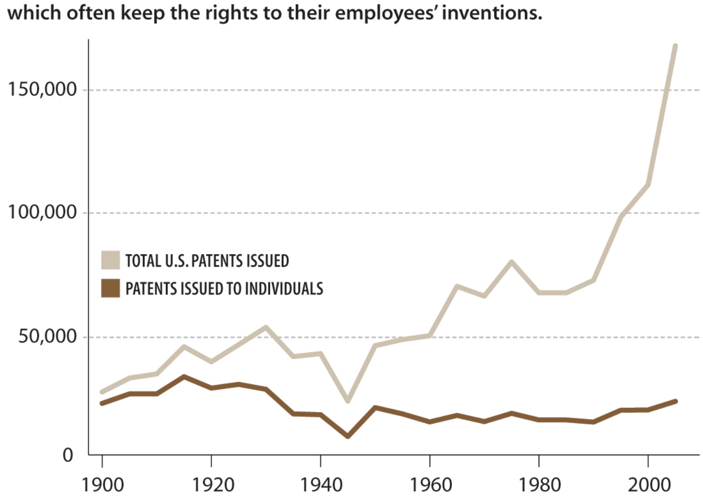
Myhrvold and Jung have been highly secretive about exactly who is involved with the Invention Factory, and their interviews with *Technology Review* mark their first public remarks on the subject. They will say that on the still-in-formation board of advisors is Dean Kamen, the New Hampshire-based inventor who earned recent fame for his Segway personal transporter.

Since Kamen already has his own operation, Deka Research and Development, which includes an extensive laboratory, he says he'll remain an advisor rather than one of the staff inventors. Even more than creating new ideas, Kamen sees the goal of the Invention Factory as applying existing inventions to unforeseen problems. "There is a large amount of intellectual property developed around specific applications that might have bigger applications in new fields," he says. "Many of the six million [United States-issued] patents solved a need but now could be applied to a different need. Clearly, if there was a way to systematize the application of new intellectual property, it would be tremendous."

So instead of signing up well-entrenched inventors like Kamen, Myhrvold and Jung have been on the lookout for accomplished inventors who don't already run their own large enterprises; they're especially interested in inventors who have proved their mettle by winning patents worth millions of dollars in royalties and license fees. "Dozens of these people have made enormous amounts of money," Myhrvold says. In return for their involvement, these independent inventors would

Lone Inventors Lag Behind

Independent inventors once earned most U.S. patents. But since the 1920s, loners have been outgunned by corporate, government and university labs, which often keep the rights to their employees' inventions.



receive an entire legal and support infrastructure: attorneys to file patent applications, draft licensing agreements and litigate disputes; and an administrative staff that can perform patent searches and other work. In addition, the company would match different inventors together on particular projects in order to maximize the chance of a breakthrough. "A lot of good inventors can be great if paired with a great inventor," says Jung.

Among the first inventors to pledge their involvement is Leroy Hood, 63, who developed the automated DNA-sequencing machine while at Caltech in the 1980s. In late 1999, after eight years at the University of Washington, Hood left academia to start the private Institute for Systems Biology in Seattle. "He's got some stock in companies, but has he gotten what he's worth?" Myhrvold asks. "Probably not." Hood says he is especially interested in brainstorming new inventions at "the intersection of information technology and biology." "That is something that can be done uniquely with Ed and Nathan," he says. "I'm committed to exploring this opportunity."

Myhrvold cites Ronald A. Katz, a Los Angeles-based inventor who has reportedly made hundreds of millions of dollars by licensing his 25-plus patents on touch-tone telephone menus to companies such as AT&T, WorldCom, the Vanguard Group, American Express, IBM and Microsoft, as another example of the kind of innovator he's looking for. Brian Rivette, of Ronald A. Katz Technology Licensing, would only confirm that Katz knows Myhrvold.

Even though many of the inventors they want to woo are already well heeled, Myhrvold and Jung think the Invention Factory's compensation plan, one they say may never have been attempted in the past, will be appealing. At most corporate labs, researchers sign over rights to royalties and licensing fees in return for a steady salary. Invention Factory inventors will also receive modest salaries—after all, says Jung, "you can't take a future royalty stream to the grocery store"—but they will split licensing revenue or royalties on their inventions with the company (though Jung and Myhrvold won't specify the percentages).

In attempting to make a business out of inventing, the Invention Factory will refrain from launching Silicon Valley-type startups, Myhrvold adds. Product development and marketing cost too much, he says, and would distract the enterprise from the inventing of new things. "The world has lots of companies to take products to market," he says. "When you set out to create important inventions as your primary goal, it takes you to a different place."

"The lone inventor is **not** something that belongs in the **age of dinosaurs.** People can do something with their technology **without** large corporations."

LUCRATIVE IN THE LONG RUN

Although Myhrvold's overall concept for the Invention Factory may sound eminently workable, observers who have not been privy to the details of the plan have their doubts. Ronald J. Riley, an independent Michigan inventor of numerous factory assembly-line technologies and the president of the Professional Inventors Alliance, a nonprofit educational group, warns that it would be risky for one organization to try to license patents and protect intellectual property across a variety of industries. "I'm not saying it can't be done," Riley says. "But it is difficult because different industries require different sets of skills and different sets of contacts." In the past, Riley adds, others firms have tried to form patent enforcement funds, in which investors fund patent preparation fees and litigation in return for a share of future profits. "The trouble," Riley says, "is that the average time frame for making any money from a valuable patent is five to 10 years"—requiring investors with abnormal patience.

Myhrvold could also run into resistance from inventors themselves, who tend to be a fiercely independent folk. "Inventors have big egos, and I'm no exception," says Riley. "I know inventors who are flat out incapable of working with other people." Secrecy can be another thorny issue, notes Arthur Molella, director of the Smithsonian Institution's Lemelson Center for the Study of Invention and Innovation. "A lot of independent inventors have been burned in the past," he says. "They may be reluctant to share their ideas."

But a few ventures similar to the Invention Factory in one respect or another have succeeded, at least for a time. Before its demise in 2000, Interval Research, the Silicon Valley lab established by Microsoft cofounder Paul Allen in 1992, spun off companies such as Purple Moon, a children's gaming company based on the ideas of computer game developer and theorist Brenda Laurel. Battelle, the nonprofit lab in Ohio, and the now struggling Cambridge, MA, consulting firm Arthur D. Little have for years evaluated other companies' inventions, nurtured them and helped license them to corporations and government agencies—in addition to coming up with their own inventions. "The lone inventor is not something that belongs in the age of dinosaurs," says Jules Duga, an expert on the economics of research and development with Battelle. "I'm a firm believer that people can do something with their technology without being affiliated with large corporations."

And a small Boston-area partnership of four inventors called Invent Resources has been in business for nearly a decade, typically working on a contract basis for corporations. "We develop intellectual property and approach companies with our ideas," says company president Richard Pavelle, "or they come to us with a problem, and we come up with a solution." The partnership, which has so far generated more than 100 patents, from a quiet electric pencil sharpener to a superfast rest room hand dryer to a tornado-warning system, retains all patent rights to its inventions, while its corporate clients typically purchase options on projects they back and then license the innovations that suit their needs.

If Nathan Myhrvold can manage to sign up enough inventors, obtain enough funding and work through all the legal ramifications, his Invention Factory would likely run in a similar fashion—but on a larger scale, and with his inventors scattered across a far greater geographic region. Myhrvold is both enthusiastic and realistic about the challenge. "This wouldn't have a quick payoff," he says. "The more powerful the invention, the longer it often takes to have a big impact. So this is not a get-rich-quick scheme; but in the long run it can become unbelievably lucrative. What a great time this is to come up with new ideas!" TR

To join an online discussion of this article, visit
www.technologyreview.com/forums/invention

Window of opportunity: New tools are giving independent inventors the chance to make a comeback, Myhrvold says.

DEMO

At the Palo Alto Research Center, Mark Yim's modular robots adapt to new environments by changing their very anatomy.

PHOTOGRAPHS BY EMILY NATHAN

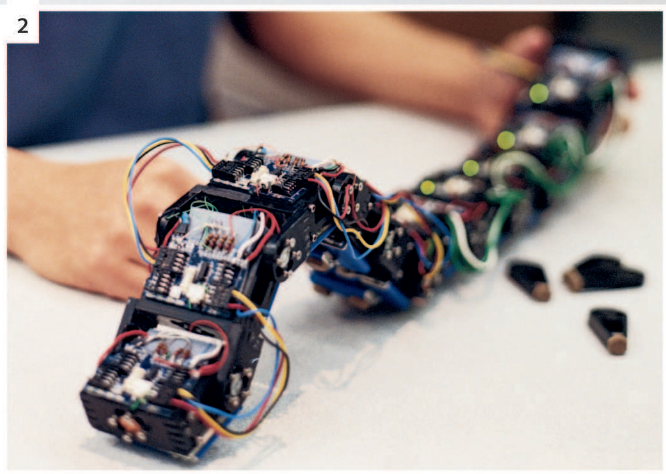
RECONFIGURABLE ROBOTS

If you think the liquid android in *Terminator 2*—the one that reassembled itself after being smashed into tiny droplets—is centuries off, think again. Robots built from small, intelligent, interchangeable modules are already squirming their way off the drawing boards in labs around the world, including Mark Yim's Modular Robotics Laboratory at the Palo Alto Research Center. A senior researcher at PARC, Yim has developed a bestiary of versatile "PolyBots," proving for the first time that different groupings of identical modules can locomote like a snake, a spider, a lizard, a wheel, and more. To Yim, these itinerant prototypes are early steps toward Proteus-like machines that adapt to new environments—say, the surface of a remote planet—by altering not simply their behavior but their very anatomy.

Future modular robots could also help out closer to home, Yim predicts: "Make my bed, do the dishes, clean the house, change the oil in my car. That kind of thing would be very hard for a robot with a fixed shape, but if you have the ability to adapt and change your shape, that opens up a wide variety of tasks." *Technology Review* senior editor Wade Roush visited Yim and his team and got a first-hand look as the early predecessors of such shape-changing machines crept, crawled and rolled around the laboratory. TR

1

2



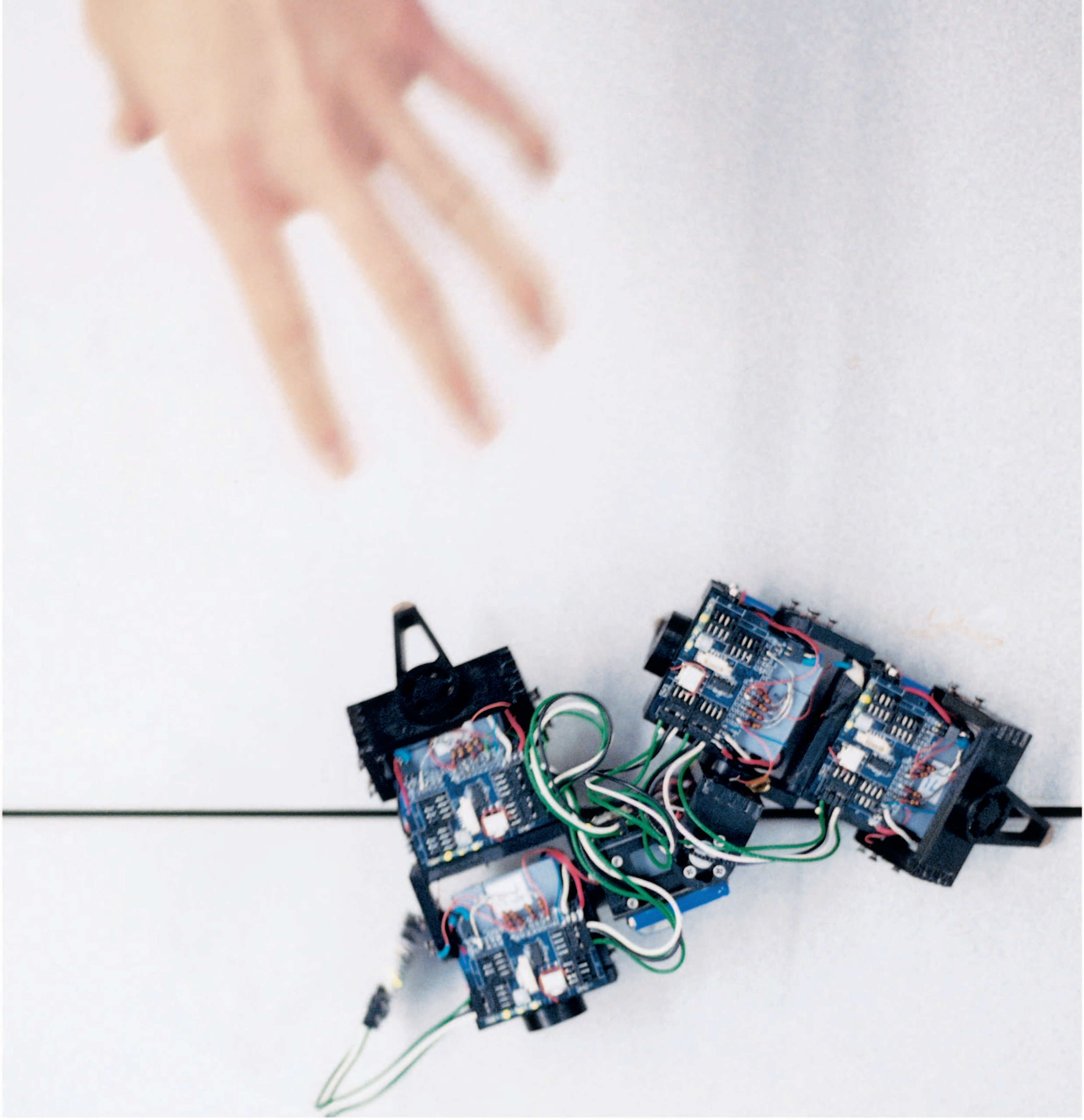
1. CREATING CONNECTIONS. Yim's first-generation or "G1" PolyBots are "a test bed for doing experiments with different gaits," he says. Yim connects several G1 modules by hand to produce different robot body shapes, beginning with a snake's. He pauses before attaching the next module, which is essentially a squat box-shaped hinge. "These guys have basically two parts: the modules and the wires that connect them. Each module has a computer and four identical connectors" on its top, to which green and white wires are attached. "The wires pass power and communications from module to module."

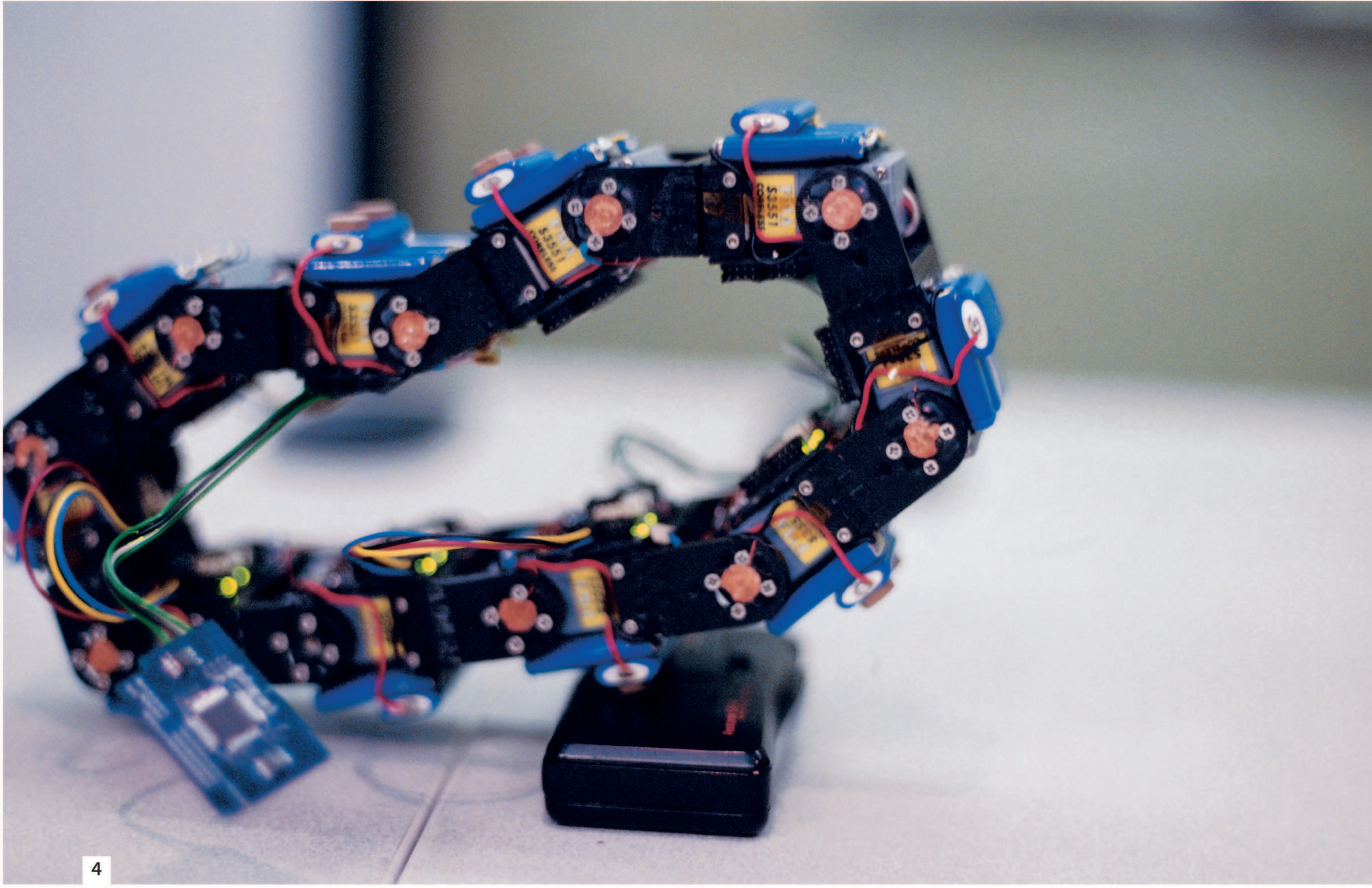
A motor in the module, driven by the onboard computer, can swivel each of the hinge's two halves in either direction, Yim says, flexing the device's joint with his hands. As the snake grows before him, Yim explains that the modules are actually capable of snapping together on four sides, "so they can form a cross as well as a chain." Small wires touch when two modules are joined—"That's how a module sees who its neighbors are."

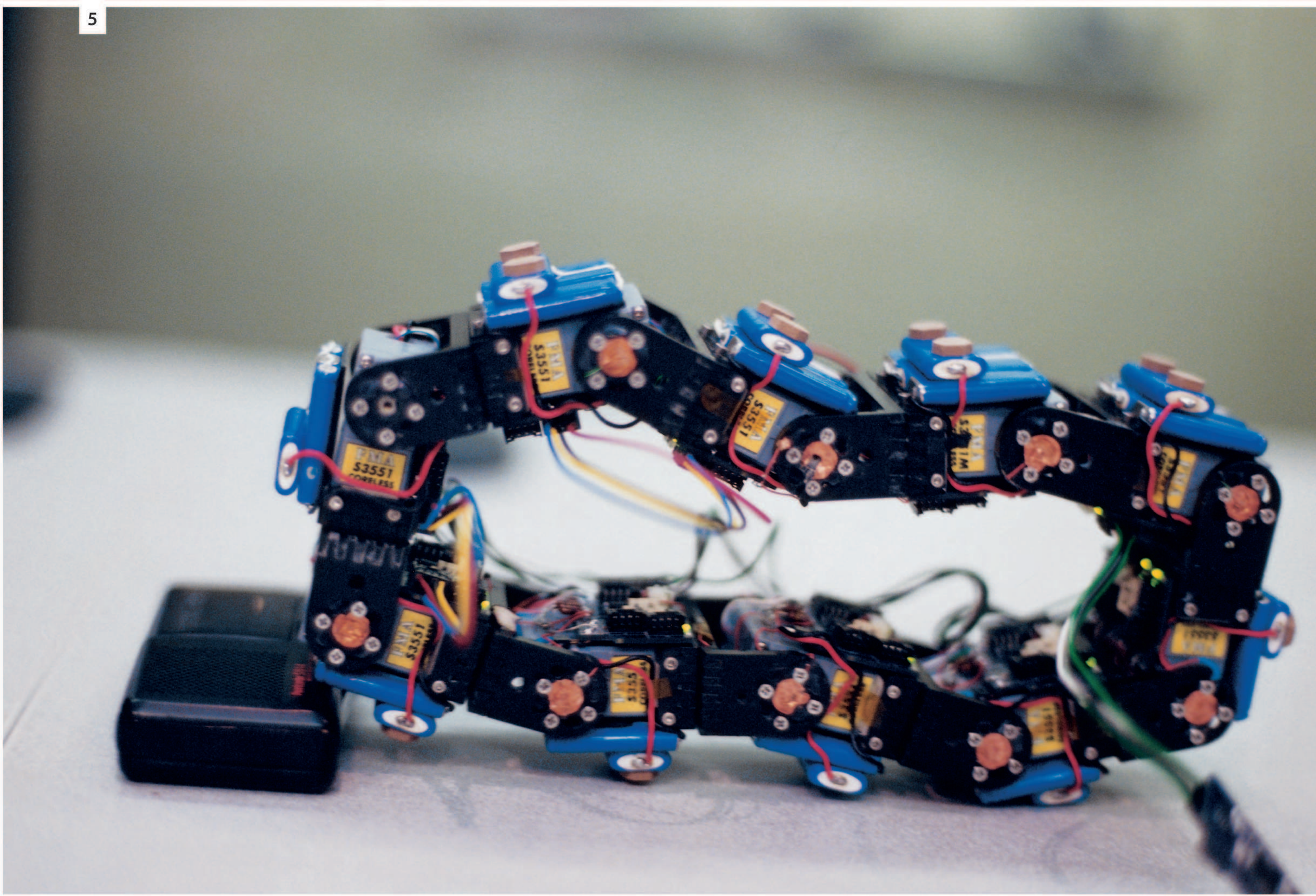
2. FROM MANY, ONE. Though each module stores its own basic software for detecting neighboring modules and actuating its motor, Yim says, the newly formed snake needs a central "brain" to organize the modules' movement. Once Yim finishes assembling the chain, he attaches the brain—a small blue circuit board dangling from a couple of wires *(not visible in this image)*—to an open connector on one of the modules.

The snake sits silently for a few seconds, its green light-emitting diodes blinking. "What's happening," says Yim, "is that each module is talking to the others and to the brain. They're figuring out that 'All of us modules are in a line, so this means we're in the shape of a snake,' and the brain is about to say, 'Okay, I recognize the snake shape, now let's move like a snake.'" At that moment, the chain springs into life; its modules bend upward and downward in waves, driving the assembly forward with each undulation. "Kids actually love it," says Yim. "It looks very biological. It crawls over their hands, and they touch it and go, 'Eeww.'"

3. WALK LIKE A REPTILIAN. Yim pulls the snake apart and joins the modules together again in an H shape, snapping a three-centimeter plastic leg onto each of the H's corners. "It recognizes that it has four legs, so now the brain commands it to move like a four-legged animal," he says. The motions are patterned after a lizard's walk, Yim explains, bending from side to side at the waist to help push his hands alternately above his head, alligator-fashion—a trick that allows the robot to move using only five motors, rather than the eight most four-legged robots require. The headless quadruped marches briskly across the table; Yim snatches it back up before it can tumble over the side.

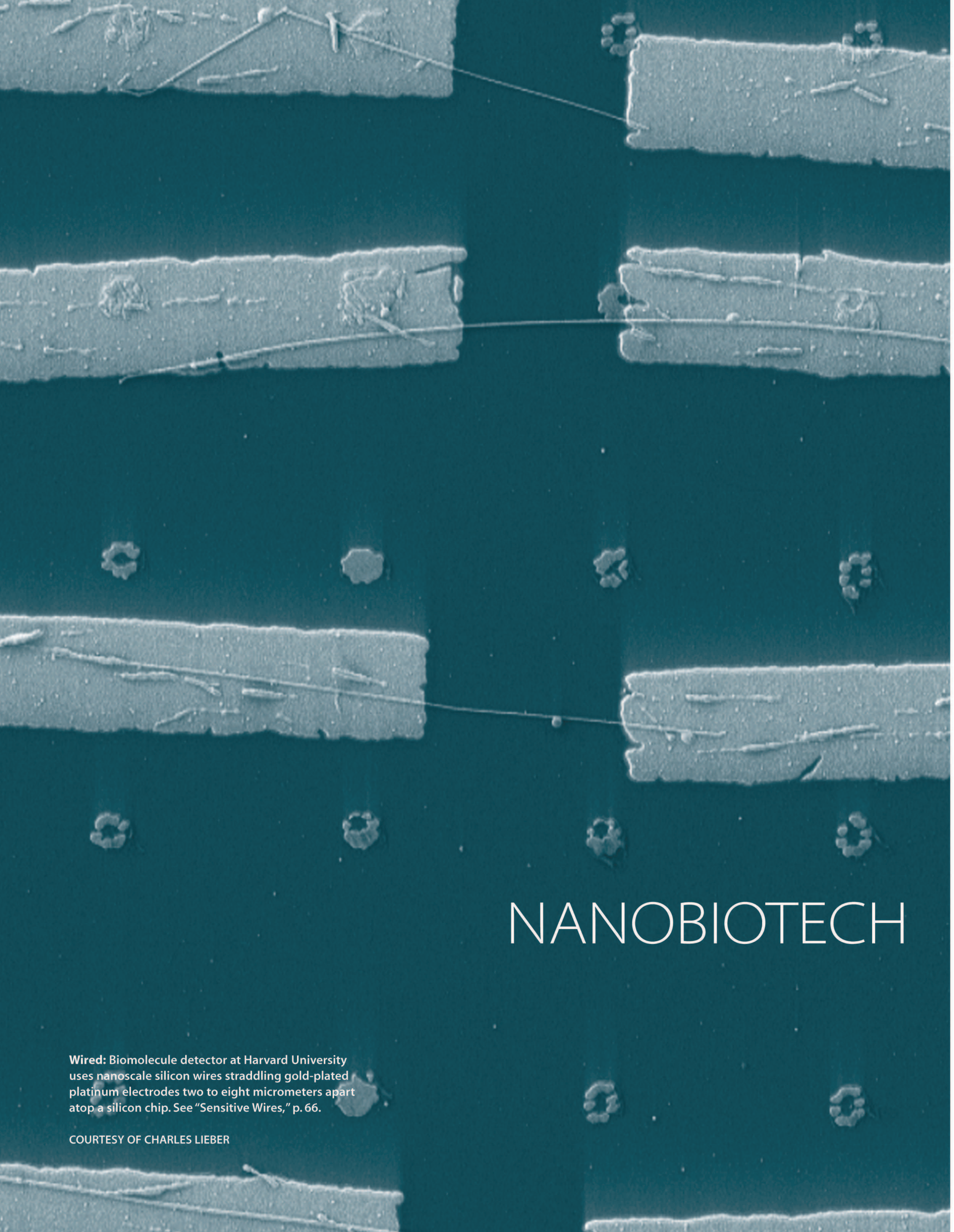



4


5

4-5. ON A ROLL. "Now what we're going to try to do is hook it up in a loop," says Yim, tearing apart the lizard and reconstructing the snake. He then joins the snake's ends, and the modules sense that "each one has a neighbor on both its head and its tail, and there's no end, and therefore it's a loop." Yim places the loop on the table, where it steamrolls over a tape recorder. Though it appears that all the modules are working together, "There are actually only four modules running their motors at one time," Yim notes. "No matter how many modules we have in the loop, it would still just be four. The inactive motors can be turned off to save power and to keep them from fighting each other. And with the motors off, the modules are looser, so they bend and conform to the terrain the loop covers. With more modules in the loop it could do things like climb on stairs and take the shape of the steps."

6. SELF-BUILDING BLOCKS. Robots that know when they've been snapped together are all well and good, but the ideal modular robot would reconfigure itself. That's the idea behind Yim's "G2" PolyBots. These modules feature the same motorized-hinge design found in G1 devices, though in this case the motor protrudes from the module's side in a black housing. But G2 modules have infrared sensors to guide them as they detach and reattach, forming new shapes without any outside help. "The G2 experiments are leading to further autonomy" for modular robots, Yim says. "Their ability to morph from shape to shape makes them ideal for unstructured situations, like search and rescue in bombed or earthquake-damaged buildings. Ultimately, though, we hope that the PolyBots' commercial successors will be versatile enough to handle the mundane tasks that average consumers have."



Wired: Biomolecule detector at Harvard University uses nanoscale silicon wires straddling gold-plated platinum electrodes two to eight micrometers apart atop a silicon chip. See “Sensitive Wires,” p. 66.

COURTESY OF CHARLES LIEBER

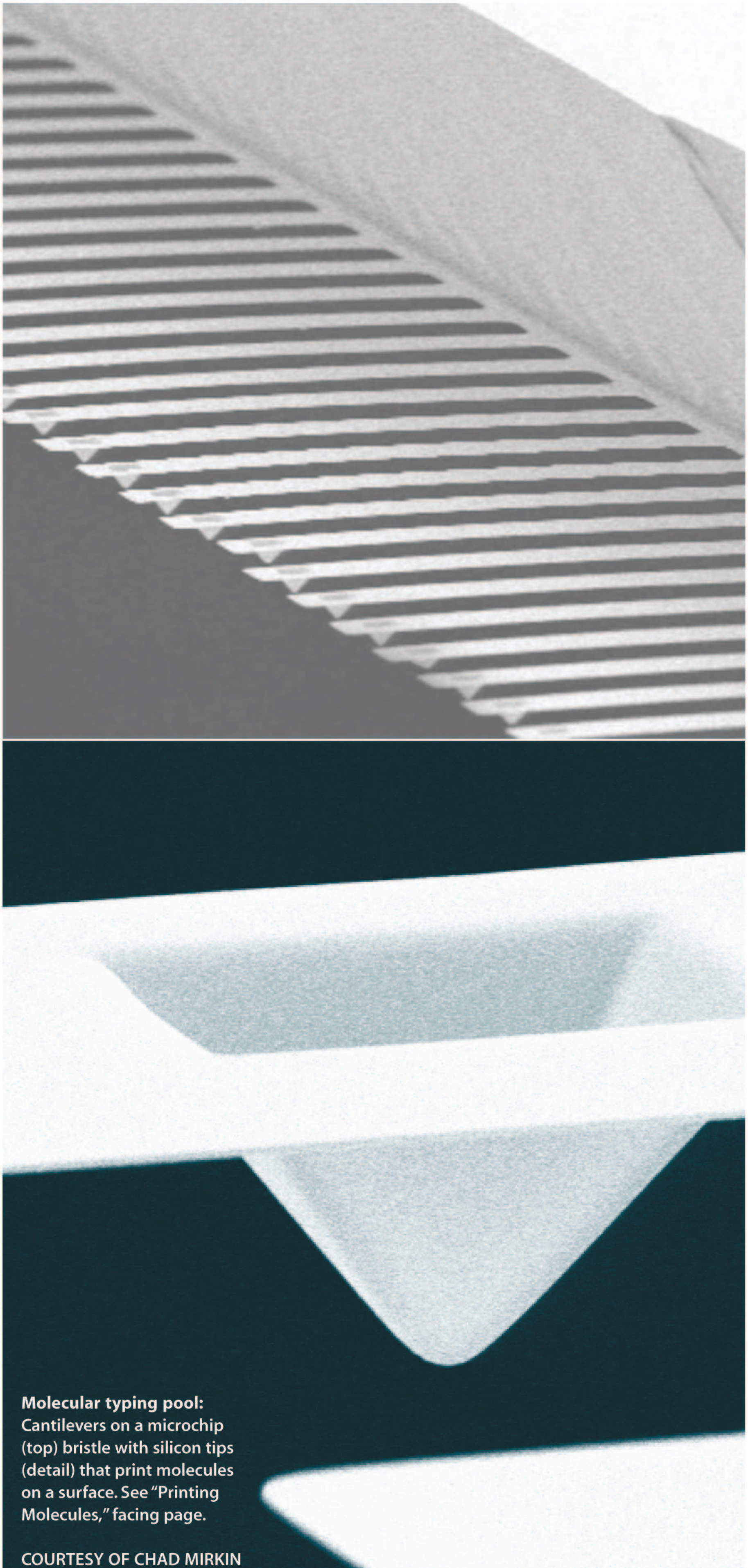
NANOBIOTECH MAKES THE DIAGNOSIS

By Alexandra Stikeman

WANT TO DETECT A SINGLE ANTHRAX SPORE? A TELLTALE CANCER PROTEIN? THE CONVERGENCE OF NANOELECTRONICS AND BIOLOGY IS PRODUCING BIOSENSORS OF EXQUISITE SENSITIVITY.

Gazing at an electrical meter, Yi Cui, a graduate student in the Harvard University lab of chemist Charles Lieber, waits for evidence of a remarkable feat in simple, ultrasensitive diagnostics. His target is prostate cancer. His new tool is a microchip bearing 10 silicon wires, each just 10 nanometers (billionths of a meter) wide. These nanowires have been slathered with biological molecules with an affinity for PSA, a protein all too familiar to men of a certain age as the telltale sign of prostate cancer. If the experiment works according to plan, when the PSA molecules bind to the nanowires, there will be a detectable electrical signal.

Cui washes a solution containing prostate cancer proteins over the chip. Immediately, the meter registers subtle changes, indicating not only that the device has detected the protein, but that it detected perhaps as few as three or four molecules, instantly and with minimal sample preparation—a previously unheard-of feat. The implications for diagnostics are enormous. A successful prostate cancer test must distinguish between normal and elevated protein levels. Ultrasensitive sensors like



Molecular typing pool: Cantilevers on a microchip (top) bristle with silicon tips (detail) that print molecules on a surface. See "Printing Molecules," facing page.

COURTESY OF CHAD MIRKIN

Lieber's could discern the slightest increase; what's more, they could do so in cheap, disposable tests that patients could use at home between visits to the doctor. "If I were at risk for a particular cancer, I wouldn't want to take a chance and wait for some cancer cells to grow wildly out of control over a year because the previous test missed it," says Lieber.

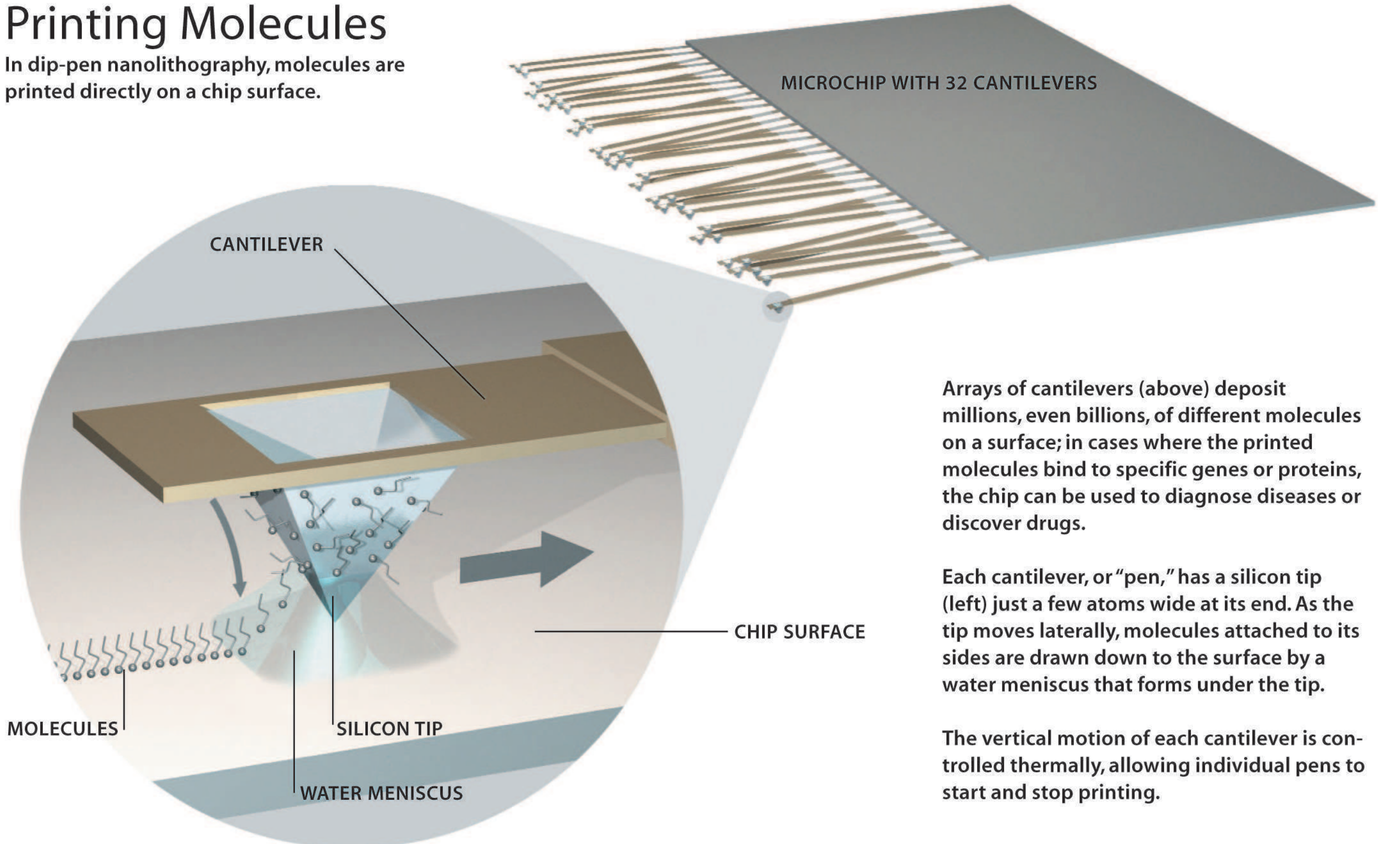
Though this nanowire device is just an experimental prototype, it is at the forefront of a growing effort at labs around the world to marry nanoelectronics and biology into a new field called nanobiotechnology. This hybrid discipline is producing a variety of tools—from arrays of tiny sensors that can detect specific biological molecules to microscopic systems carved out of silicon that can read individual strands of DNA—capable of providing a new window on biological molecules.

The implications for medicine and biotechnology are myriad. Besides sniffing out the barest whiffs of disease—or perhaps detecting a single spore of anthrax—these devices could provide far faster and easier diagnosis of complex diseases. For example, they could provide early warnings about heart attacks, whose calling cards are subtle changes in the mix of dozens of proteins. Alternatively, a single microchip could provide a comprehensive diagnosis from a drop of blood. And for drug researchers, nanobiotech gadgets could mean new tools for discovering and evaluating potential drugs more rapidly, by screening millions of different drug candidates at once. Some of these more ambitious goals will likely take years to achieve, but nanobiotech could lead to real devices that will begin replacing cumbersome lab-based procedures with cheap, accurate microchips in as little as two years.

These first products—chips rigged to detect a specific disease or cluster of genetic disorders—are already being developed at nearly a dozen nanobiotech startups *(see "Sensing Success," p. 66)*. Larry Bock, CEO of Palo Alto, CA-based startup Nanosys [*TR* board member Robert Metcalfe is a Nanosys cofounder and director. Ed.], which has licensed Lieber's technology, predicts his company will market a commercial sensor within three years, first for use as a research aid to rapidly screen potential drugs, and later as a cheap, disposable at-

Printing Molecules

In dip-pen nanolithography, molecules are printed directly on a chip surface.



Arrays of cantilevers (above) deposit millions, even billions, of different molecules on a surface; in cases where the printed molecules bind to specific genes or proteins, the chip can be used to diagnose diseases or discover drugs.

Each cantilever, or "pen," has a silicon tip (left) just a few atoms wide at its end. As the tip moves laterally, molecules attached to its sides are drawn down to the surface by a water meniscus that forms under the tip.

The vertical motion of each cantilever is controlled thermally, allowing individual pens to start and stop printing.

home test for prostate cancer and perhaps other cancers. "People talk about all the wonders of nanotechnology but then say it's not going to happen for another 20 years," says Chad Mirkin, a chemist and director of the Institute for Nanotechnology at Northwestern University. "But that's absolutely incorrect for things like diagnostics. You're going to see products on the market in the next two years."

Power in Numbers

Biology and electronics have long existed in separate universes. But because biological molecules, like DNA and proteins, are roughly a few nanometers in size, and because physicists and chemists are now learning how to make electronic devices on exactly that size scale, these universes are colliding. The result is a new class of devices that combine the ability of biological molecules to selectively bind with other molecules with the ability of nanoelectronics to instantly detect the slight electrical changes caused by such binding. "What's really interesting about this technology is that it allows one to take the inorganic components that normally would be nestled inside an electrical chip and combine them with biological molecules," says Paul Alivisatos, scientific cofounder of Nanosys and a chemist at the University of California, Berkeley.

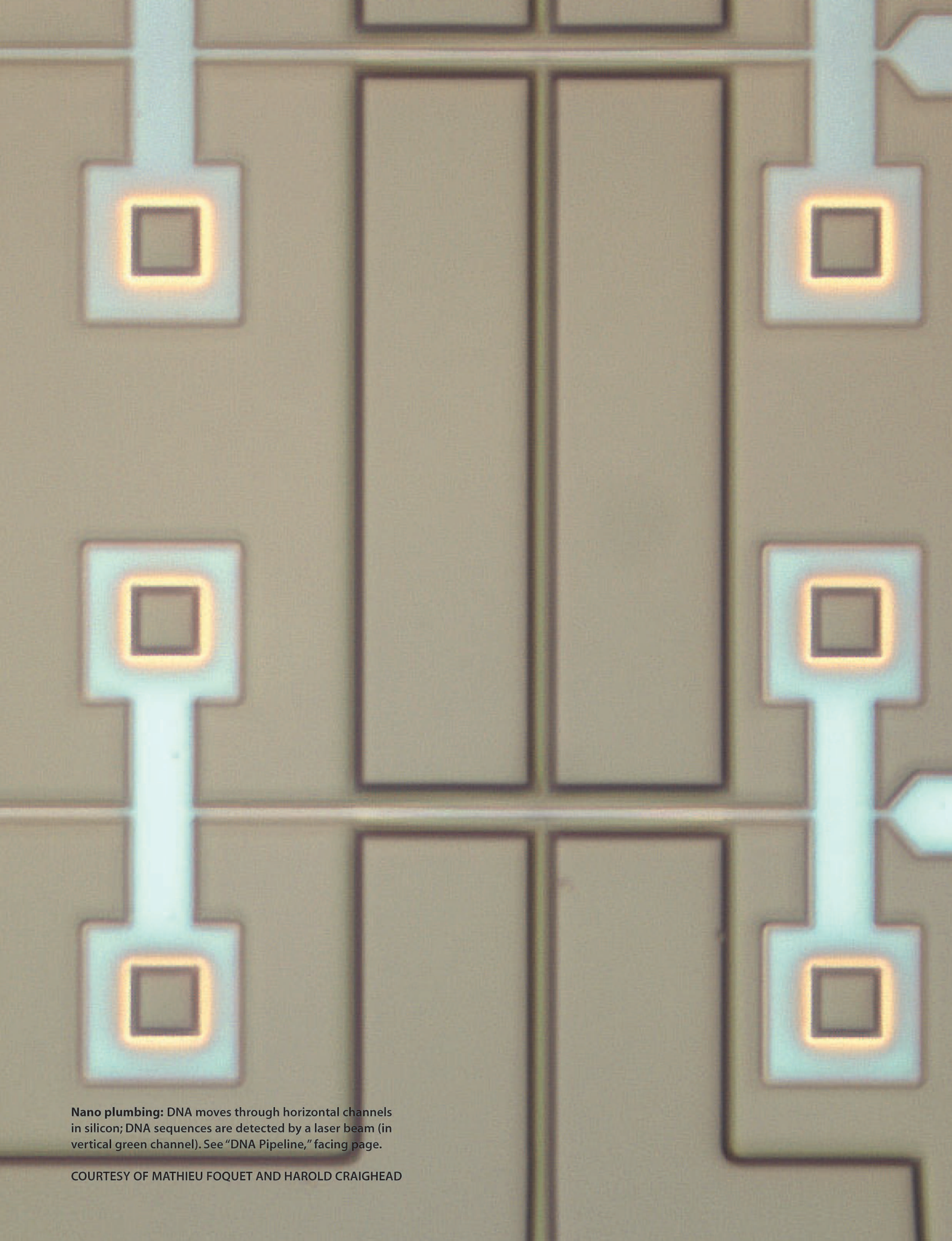
Indeed, nanoelectronic devices like the one built in Lieber's lab *(see "Sensitive Wire," p. 66)* could do away with the elaborate apparatus now needed for ultrasensitive detection. "If you wanted to do single-molecule detection in a lab today, you would need a laser the length of a desk and a lot of sophisticated optics, chemical labels to amplify the signal enough to be able to see it," Bock says.

Shrinking down such ultrasensitive devices enough that they could be put on chips could have numerous applications in diagnostics. Stanford University chemist Hongjie Dai, for example, has built a device that can detect glucose with a single carbon nanotube, a large carbon molecule with excellent electrical properties *(see "The Nanotube Computer,"* TR *March 2002)*. The glucose molecules react with molecules on the surface of the nanotube, creating electrical signals that correspond to glucose concentrations, he says. Though only a proof of concept today, such a device could be developed into an implantable glucose sensor for diabetics. In December, Dai launched Molecular Nanosystems in Palo Alto, CA, to commercialize nanotube-based devices including biosensors.

For many applications, though, what's really needed is not a lone nano detector but a dense array of them. That way, you can rapidly look for thousands, even millions, of different biological molecules in a single drop of blood or other body fluid, allowing the diagnosis of diseases that have complex molecular signatures. One such disease is rheumatoid arthritis—an autoimmune disease with many variants, each marked by subtle differences in groups of proteins. Ideally, each variant would be fought with a slightly different treatment; in practice, sufferers today are generally treated in the same way. But, says Dai, a nano array could serve as a highly precise and discriminating diagnostic device, providing a road map for custom treatment.

These arrays of nano detectors promise advantages over existing technologies, like DNA chips, and ones under development, like protein chips. All such chips require fluorescent labeling of molecules and optical microscopes to detect the glow given off when binding occurs *(see "DNA Chips Target Cancer,"* TR *July/August 2001)*. What's more, roughly a thousand molecules must bind to each sensing element to create the glow. With nanoelectronics, no bulky, expensive

JOHN MACNEILL; SOURCE: NANOINK



Nano plumbing: DNA moves through horizontal channels in silicon; DNA sequences are detected by a laser beam (in vertical green channel). See "DNA Pipeline," facing page.

COURTESY OF MATHIEU FOQUET AND HAROLD CRAIGHEAD

equipment is needed, and instant detection of just a few molecules is possible.

Sticky DNA

But sensors with nanoscale features can only succeed if they are "sticky" enough to grab onto molecules of interest. Northwestern's Mirkin sees value in gold: specifically, nanoscale gold particles, to which he affixes multiple fragments of DNA that can latch onto DNA targets. Each gold particle becomes "like Velcro," he says. In the next 18 months, Mirkin says, he and his colleagues will build a simple, doctor's-office diagnostic device capable of instantly diagnosing diseases or predispositions to disease, depending on what DNA fragments are used on the device. "Chips will be built for panels of diseases," says Mirkin, including sexually transmitted diseases, cystic fibrosis and genetic predispositions to colon cancer and blood hypercoagulation (blood that clots excessively).

Mirkin's prototype chip, under development by Northbrook, IL-based Nanosphere, a company he cofounded, uses DNA deposited between electrodes on a microchip to recognize targets of interest. A sample is mixed with those "Velcro" gold particles and washed over the chip. If the sample contains the targeted DNA—say, genetic material from the syphilis bacterium—the DNA will bind to those sticky gold particles and then to the DNA fragments between the electrodes. The gold particles close the circuit and produce a detectable signal. The more electrode sensing elements per chip, the more diseases—or genetic predispositions—can be detected.

Mirkin's group is adapting a process known as dip-pen nanolithography to gain the ability to literally "print" DNA molecules between electrodes just 200 nanometers apart *(see "Printing Molecules," p. 63)*. Mirkin hopes to pack hundreds, even thousands, of electrode sensing elements on one chip.

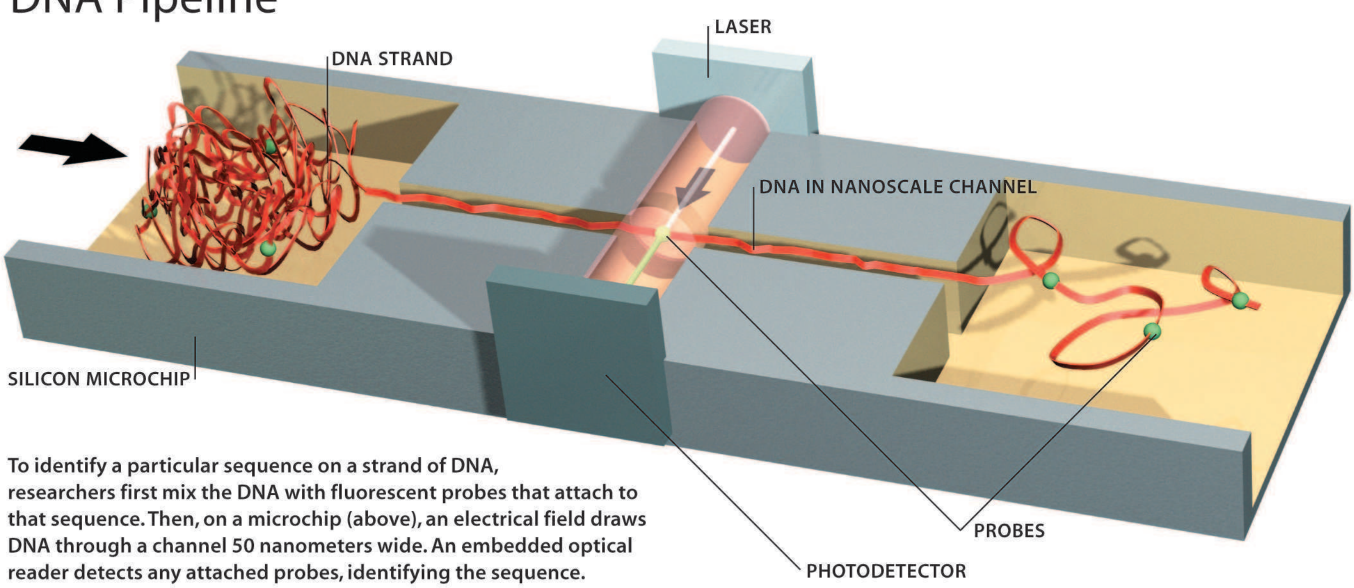
Mirkin's technology can find specifically targeted DNA in a sample. But if you could actually grab a single piece of DNA and directly "read" its genes, you could, in theory, identify any gene, or even complex gene patterns. Using tools adapted from semiconductor manufacture, physicist Harold Craighead of Cornell's Center for Nanobiotechnology and his former postdoc Stephen Turner built a silicon chip containing tiny channels, each 50 nanometers in width and depth *(see "DNA Pipeline," below)*. The channel is so small that a single strand of DNA can barely squeeze through—and that's just the point. An electric field causes the normally coiled ball of DNA to bump into the channel, uncoil and thread its way down.

Once grabbed, the DNA needs to be "read"—to see, for example, if it contains a specific sequence. To make a sequence legible, researchers add fluorescent-labeled DNA probes to the sample beforehand; the probes bind to the target sequences. As each molecule of DNA wiggles its way down the channel, an optical detector identifies the fluorescent labels passing by. "We're treating the DNA like it's a recording medium," says Turner, who is now president of Nanofluidics, a startup trying to commercialize the Cornell technology. "And just like a tape player, we're playing the DNA." While the Cornell researchers currently use an external optical microscope to read the "tape," they hope to build an optical reader directly onto the chip using optical fibers. Turner expects to have a working device within the next few years.

Because the tools for making these tiny channels rely on the same standard equipment used to fabricate silicon chips for microelectronics, Turner envisions making nanofluidic chips with thousands and even millions of channels and optical fibers. With such devices, Turner says, doctors could one day take a drop of blood from a patient, drop it on the microchip and rapidly scan the DNA in

"PEOPLE TALK ABOUT THE WONDERS OF NANOTECHNOLOGY BUT THEN SAY IT'S NOT GOING TO HAPPEN FOR ANOTHER 20 YEARS. BUT THAT'S ABSOLUTELY INCORRECT FOR THINGS LIKE DIAGNOSTICS. WE'RE GOING TO SEE PRODUCTS ON THE MARKET IN THE NEXT TWO YEARS."

DNA Pipeline

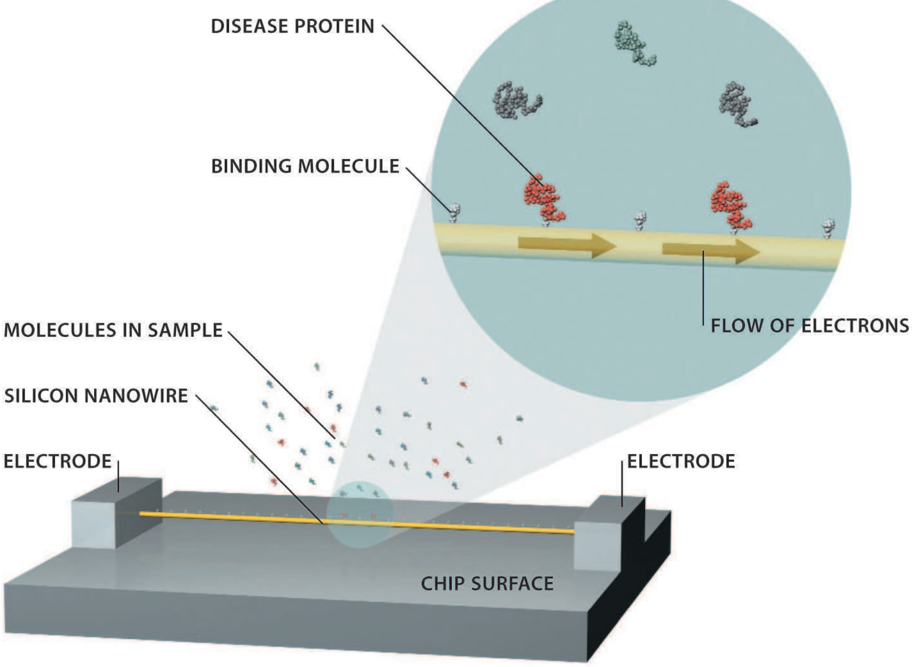


To identify a particular sequence on a strand of DNA, researchers first mix the DNA with fluorescent probes that attach to that sequence. Then, on a microchip (above), an electrical field draws DNA through a channel 50 nanometers wide. An embedded optical reader detects any attached probes, identifying the sequence.

JOHN MACNEILL; SOURCE: NANOFLUIDICS

Sensitive Wire

To detect a disease-related protein in a blood sample, a silicon wire just 10 nanometers wide is coated with biomolecules that bind only to that protein (below). When the disease protein binds to a molecule on the wire (inset), the wire's conductance changes, providing an instant electric signal.



the sample for genetic markers of disease. The device could also help doctors choose just the right drugs for the patient.

DNA Control

In the marriage of nanoelectronics and biology, the most extreme vision involves affixing electronic gadgets directly to molecules. To show how this might work—and why it might be useful—a team at MIT's Media Lab, led by physicist Joseph Jacobson and biomedical engineer Shuguang Zhang, affixed gold particles, each only 1.4 nanometers in diameter, to a piece of DNA. Each gold particle served as a tiny antenna. The researchers then exposed the DNA to radio frequency magnetic fields, causing the particles to heat up, and the double-stranded DNA to break into two strands. When they removed the magnetic field, the strands came back together immediately. "Now we have a very powerful and useful tool that can control things at the molecular level," says Zhang. "So far, there are no tools that can do this. To be able to control one individual molecule in a crowd of molecules is very valuable."

That value, adds postdoc Kimberly Hamad-Schifferli, arises largely from the potential ability to turn genes on and off. To do that, the MIT researchers could attach fragments of DNA to gold particles. When added to a sample of DNA, the fragments would bind to complementary gene sequences, blocking the activity of those genes and effectively turning them off. Applying a magnetic field would then heat the gold particles, causing their attached fragments of DNA to detach, in effect turning the genes back on. Such a tool could give pharmaceutical researchers a way to simulate the effects of potential drugs, which also turn genes on and off. MIT recently licensed the technology to a biotech startup, Waltham, MA-based engeneOS.

Although remote control of DNA may sound more like a parlor trick than something your doctor might use, such experiments are demonstrating that nanoelectronics can interact with biology in powerful ways. Materials like nanowires and nanotubes, extensively researched by physicists and chemists in recent years, are now in the hands of biomedical engineers like MIT's Zhang—with huge implications for everything from drug discovery to diagnosis of diseases like prostate cancer. While it's difficult to predict winners among these many technologies, Berkeley's Alivisatos, for one, says, "I think these things are all going to find competitive niches."

Fast, cheap microelectronics revolutionized the world of computing and information technology. Whether nanoelectronics can revolutionize medicine remains uncertain. But the gap between electronics and biology is fast closing, and biomedical researchers and even physicians will soon have tools to probe life's basic molecules in ways that seemed like fantasy just a few years ago. TR

Sensing Success

Some companies in nanobiotech

COMPANY	TECHNOLOGY SOURCE	STRATEGY
Agilent Technologies (Palo Alto, CA)	Harvard University	Materials with nano-sized pores for analyzing DNA
engeneOS (Waltham, MA)	MIT	Gold nanoparticles for remote control of biological molecules
Molecular Nanosystems (Palo Alto, CA)	Stanford University	Carbon nanotubes for sensing biological molecules
Nanofluidics (Ithaca, NY)	Cornell University	Chips with nanoscale channels for analyzing DNA
NanoInk (Chicago, IL)	Northwestern University	Dip-pen nanolithography for designing biological molecules and structures
Nanosphere (Northbrook, IL)	Northwestern University	Electrode/gold nanoparticle detectors for sensing DNA and pathogens
Nanosys (Palo Alto, CA)	Harvard University	Nanowires for sensing biological molecules
SurroMed (Mountain View, CA)	Pennsylvania State University	Nanobarcodes for labeling biological molecules
U.S. Genomics (Woburn, MA)	U.S. Genomics	Nanocrystalline lattice for analyzing DNA

INFOGRAPHIC BY JOHN MACNEILL; SOURCE: NANOSYS

AGENDA

2002 TR100 SYMPOSIUM AND AWARDS CEREMONY

8:00 - 8:30 **Continental Breakfast**

8:45 - 9:30 **Morning Keynote**

CLAYTON CHRISTENSEN
PROFESSOR OF BUSINESS ADMINISTRATION, HARVARD BUSINESS SCHOOL
AUTHOR, *THE INNOVATOR'S DILEMMA*

This session will provide you with a preview of what's new since *The Innovator's Dilemma*. Professor Christensen has come to believe that innovation is much less random than many have supposed. He will describe the variables that affect the probability of success, which management can capably understand and control.

9:45 - 11:00 **Panel Discussion—Transformative Technologies**

MODERATED BY: CONSUELO MACK, CNBC
SPEAKERS TBD

This panel will reflect the scope of the TR100. CEO panelists from our core segments will discuss the power and relevance of these key technologies as engines of economic growth.

11:00 - 11:15 **Break**

11:15 - 12:15 **Security, Privacy and Technology**

MODERATED BY: STEVEN LEVY, SENIOR EDITOR, CHIEF TECHNOLOGY WRITER, *NEWSWEEK*

LEWIS M. BRANSCOMB, PROF. EMERITUS, PUBLIC POLICY AND CORPORATE MANAGEMENT, JOHN F. KENNEDY SCHOOL OF GOVERNMENT, HARVARD UNIVERSITY

KENNETH STARR, PARTNER, KIRKLAND AND ELLIS AND ADJUNCT PROFESSOR, NEW YORK UNIVERSITY SCHOOL OF LAW

NADINE STROSSEN, PRESIDENT, ACLU

CHARLES R. STUCKEY JR., CHAIRMAN, RSA SECURITY

New technologies allow individuals, corporations and government entities to monitor, track and identify employees, customers and the general public. *Technology Review* will provide a forum to discuss security and privacy in today's global economy.

12:15 - 1:30 **Lunch**

1:45 - 3:00 **Concurrent Afternoon Conversations**

These sessions will provide an in-depth perspective on the three industries that will have the most pronounced benefit from transformative technologies.

Session A **Personalized Medicine**

MODERATED BY: REBECCA HENDERSON, EASTMAN KODAK LFM PROFESSOR, MIT SLOAN SCHOOL

DARLENE SOLOMON, DIRECTOR OF THE LIFE SCIENCE TECHNOLOGIES LABORATORY, AGILENT TECHNOLOGIES

KARI STEFANSSON, PRESIDENT AND CHIEF EXECUTIVE OFFICER, deCODE GENETICS

MICHAEL D. WEST, PRESIDENT AND CHIEF EXECUTIVE OFFICER, ADVANCED CELL TECHNOLOGY

We've deciphered the human genome and moved into proteomics—the study of the individual proteins that the genes code for. Such advances anticipate the day when drugs are not only targeted at molecular workings or specific diseases but tailor-made for each individual's genetic makeup.

Session B **Beyond Pervasive Computing**

MODERATED BY: ROBERT BUDERI, EDITOR AT LARGE, *TECHNOLOGY REVIEW*

RODNEY A. BROOKS, FUJITSU PROFESSOR OF COMPUTER SCIENCE AND ENGINEERING, DIRECTOR OF THE ARTIFICIAL INTELLIGENCE LABORATORY AND CO-DIRECTOR OF PROJECT OXYGEN, MIT

RICHARD RASHID, SENIOR VICE PRESIDENT, MICROSOFT RESEARCH

DAVID TENNENHOUSE, VICE PRESIDENT AND CORPORATE TECHNOLOGY GROUP DIRECTOR, RESEARCH, INTEL CORPORATION

Pervasive computing—the idea that wired and wireless computing services and applications will be available anytime/anywhere—is becoming realized. Now, computer scientists are taking the next step: promoting proactive, or attentive, computing, in which computers and sensors don't just respond to users, but anticipate their needs—through agents, data mining, sense-making and other software advances.

Session C **Breaking the Energy Deadlock—New Technologies for a Secure and Sustainable Energy Economy**

MODERATED BY: RICHARD LESTER, DIRECTOR, INDUSTRIAL PERFORMANCE CENTER AND PROFESSOR OF NUCLEAR ENGINEERING, MIT

FIROZ RASUL, CHAIRMAN AND CHIEF EXECUTIVE OFFICER, BALLARD POWER SYSTEMS

KURT YEAGER, PRESIDENT AND CHIEF EXECUTIVE OFFICER, ELECTRIC POWER RESEARCH INSTITUTE, INC.

ARVE THORVIK, DIRECTOR, WORLD BUSINESS COUNCIL FOR SUSTAINABLE DEVELOPMENT

Decades of controversy over access, environmental impact, and economic costs have created an energy landscape characterized by glacial change punctuated by periodic domestic and international crises. Can new technologies—from fuel cells to wind turbines, improved oil and gas discovery and production methods, and intelligent power grids, buildings and transportation systems—break the impasse and lead to a reliable, low-cost and environmentally responsible energy future?

3:00 - 3:15 **Break**

3:15 - 4:30 **Introducing the TR100**

MODERATED BY: BOB METCALFE, INVENTOR OF ETHERNET AND FOUNDER OF 3COM CORPORATION, PARTNER, POLARIS VENTURES

This panel discussion will vividly illustrate the power and future of transformative technologies.

6:30 - 10:00 **Announcement of the Innovator of the Year**
Black-Tie Gala at the Hyatt Regency
Cambridge, Massachusetts

Please note: Agenda subject to change. The sponsors and management of *Technology Review* reserve the right to make any necessary changes to this program. Every effort will be made to keep presentations and speakers as represented. However, unforeseen circumstances may result in the substitution of a presentation topic or speaker. Technology Review, Inc. reserves the right to use photographs or video of any TR100 attendee for future promotions.

REGISTRATION

2002 TR100 SYMPOSIUM AND AWARDS CEREMONY

MAY 23, 2002

SYMPOSIUM
Kresge Auditorium
MIT Campus
Cambridge, Massachusetts

AWARDS CEREMONY
Hyatt Regency
Cambridge, Massachusetts

4 WAYS TO REGISTER!

FAX (617) 475-8042
Attn: Sharon Morani

MAIL *Technology Review*
TR100 Registration
Sharon Morani
One Main Street, 7th Floor
Cambridge, MA 02142

PHONE (617) 475-8069

INTERNET www.technologyreview.com/tr100

Cancellations and Substitutions

If you must cancel for any reason, we will need written notice of cancellation by Wednesday, May 1, 2002. Your registration will be refunded less a $100 processing fee. Cancellations after Wednesday, May 1, 2002, are non-refundable. You may transfer your registration to another person at any time by providing written authorization. Please send all cancellation and transfer notices to *Technology Review*, Attn: Sharon Morani, One Main Street, 7th floor, Cambridge, MA 02142. They can also be sent via fax to (617) 475-8042.

Press Information or Press Registration

For information on registering as a member of the press for *Technology Review*'s TR100 or to request press releases for this conference, please email Kristen Collins at Kristen@kmcpartners.com.

Hotel Accommodations

Technology Review has secured a special group rate at:
Hyatt Regency, Cambridge
575 Memorial Drive, Cambridge, MA 02139
Phone: (617) 492-1234
www.hyatt.com

TR100 attendees will receive the special room rate of $179 for a single or double room. Rooms are available from Wednesday, May 22, through the evening of Friday, May 24, 2002.

To make your reservations, please call the hotel directly at (617) 492-1234 and reference *Technology Review* 2002. You can also make your reservations online at www.hyatt.com.

To secure the discounted rate, all reservations must be made directly with the hotel by April 22, 2002. Reservations made after the cut-off date will be made on a space availability basis. For more information visit the Hyatt Web site at www.hyatt.com.

REGISTRATION FORM

ALL INFORMATION REQUIRED

☐ Please register me for the general session only for $1,195.

☐ Please register me for the general session AND gala awards ceremony at the Hyatt Regency for $1,495.

☐ Bring your team! When 3 people register, the 4th attends FREE! All registrations must be received at the same time. Please photocopy this form for additional registrants.

☐ I am a subscriber to the magazine. Please register me with a 10% discount! Must enter subscriber code to be eligible for this discount: ______________.

☐ I am a student. Please register me for the reduced rate of $195. Photocopy of ID required via fax or mail.

☐ I am an MIT student. Please register me for free. Photocopy of ID required via fax or mail.

☐ I will not be attending the event, but I would like to receive information about future events.

NAME ______________________________

TITLE ______________________________

COMPANY ______________________________

ADDRESS ______________________________

____

COUNTRY ______________________________

PHONE ______________________________

FAX ______________________________

EMAIL ______________________________

PAYMENT INFORMATION

☐ Check is enclosed for $__________ ☐ Credit card payment for $__________

CREDIT CARD INFORMATION

☐ Visa ☐ Mastercard ☐ American Express

CARDHOLDER NAME ______________________________

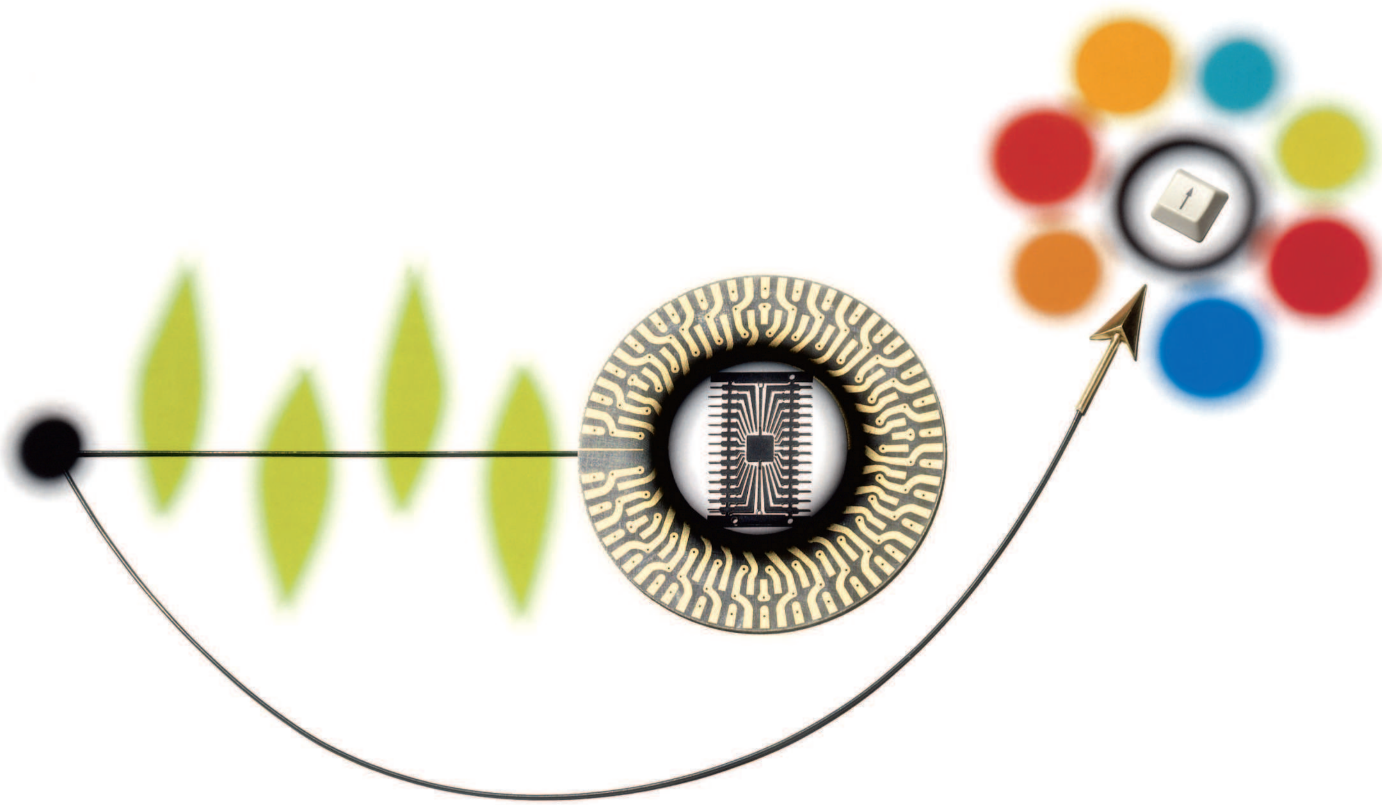
CARD NUMBER ______________________________

EXPIRATION DATE ______________________________

CREDIT CARD BILLING ADDRESS ______________________________
(IF DIFFERENT THAN REGISTRANT'S)

____

COUNTRY ______________________________



ECONOMIC BUST, PATENT BOOM

WHAT RECESSION? THE RECENT PATENT FRENZY SHOWS NO SIGN OF ABATING.

BY ERIKA JONIETZ ILLUSTRATION BY PIERRE-YVES GOAVEC

It's no news flash that the economy has been struggling for over a year, with the high-tech sector taking the biggest beating. But you'd never know it by looking at patent activity. The U.S. Patent and Trademark Office received a record flood of 344,717 patent applications in 2001, as companies worldwide beefed up their patent portfolios. The intellectual-property principle for the post-dot-com world: patent or perish.

So, too, reads the message that jumps off the pages of *Technology Review*'s latest Patent Scorecard *(p. 75)*. Based on data from CHI Research of Haddon Heights, NJ, the scorecard annually tracks the U.S. patenting activity of 150 top companies in eight key high-tech sectors. The project goes beyond mere patent numbers to rank the quality and strength of each company's portfolio according to its comparative relevance *(see "Indexing Innovation," p. 77)*.

Once again, the editors have delved deeper into U.S. patenting activity by identifying a handful of patents issued last year that are of special note. Be they stem cells that can help repair or replace any tissue in the human body, systems that speed up wireless communications or novel materials and software algorithms used to build, store and process information, these "Five Patents to Watch" *(p. 73)* represent advances that could transform a number of industries—or even create new ones.

But it's the scorecard that tells the broader story, setting the stage on which these individual dramas will play out. Its figures show that from autos to pharmaceuticals to computing and all manner of electronics, patent activity is booming. The biggest surges last year came in information technology and telecommunications. Semiconductor companies saw an average increase of 21.4 percent in the number of patents issued from 2000 to 2001. Similarly, patenting grew 20.4 percent in the telecom industry, and in computing 11.6 percent. Even more impressive, U.S.

Patent and Trademark Office statistics suggest the penchant for patents among information technology companies will continue; these three sectors saw the highest numbers of new patent applications filed in 2000, the latest year for which data are available.

As long as these companies keep investing in research and development, they will continue to patent voraciously, says Alan Fisch, patent attorney with Washington, DC, firm Howrey, Simon, Arnold and White. "If it's valuable enough to continue investing in, it's valuable enough to protect."

which the company gives $170 to any employee who submits a description of a new invention. The inventor receives an additional $1,750 if HP's lawyers choose to file a patent application on the creation—and a special plaque if the patent issues. As a result, says Steve Fox, director of intellectual property, the company has seen "considerable growth" in the numbers of invention disclosures it receives, and patent applications have doubled.

The concrete goals of the campaign are highly pragmatic: to break into the list of the top ten U.S. patentees and to

new drugs or perform diagnostic tests from microliters to nanoliters—and put the whole experimental apparatus on a single chip. Theoretically, this will enable dramatic cost savings in the time and money needed to develop drugs or diagnose diseases.

"We were fortunate enough to come into microfluidics in a time when the patent landscape wasn't as crowded as it is now," says Caliper vice president of intellectual property Matt Murphy. "We've tried to file broadly enough to cover the general path we're taking and then file aggressively."

From autos to pharmaceuticals to computing to electronics, patent activity is booming. Be they stem cells or software algorithms, these patents could transform industries—or even create new ones.

No firm more clearly epitomizes the patenting mania than IBM. For an astonishing nine years running, the company has topped the U.S. Patent and Trademark Office's list of patentees, receiving 3,454 patents in 2001—almost 10 a day. Its supremacy also extends to *TR*'s ranking of technological strength, as Big Blue dominates not just its industry category but the entire scorecard. "I definitely see this trend continuing," asserts Jerry Rosenthal, IBM's vice president of intellectual property and licensing. "We think it's what keeps us ahead of the industry."

IBM doesn't make its push for patents just for public-relations value, although that helps. The behemoth earned more than $1.5 billion from licensing income last year, all of which it plowed back into R&D, according to Rosenthal. "The problem we've got is that technology is moving so rapidly, it's hard to predict always where and what the next generation will be," he says. "So we have to patent broadly to protect ourselves." Knowing that their technology will be patented—and ultimately licensed out to other companies—forces IBM's researchers to stay one step ahead of the pack, Rosenthal adds.

More and more firms are getting the message. Hewlett-Packard hopes to use a strategy similar to IBM's to advance its position. In December 1999, the 62-year-old company launched its "Invent" campaign, a push to increase innovation and, especially, patenting. To accomplish this goal, HP vigorously promotes its "inventor incentive program," in

increase revenue by licensing the patents out to other companies. "We will move up into the top ten in the next year or two years," Fox predicts.

Although the process of patenting historically tends to be dominated by large, well-known concerns—four of *TR*'s five patents to watch come from IBM, Lucent Technologies, NEC and Microsoft—the scorecard also shows that smaller, newer companies are making inroads in fast-moving industries like biotechnology and semiconductors.

San Jose, CA-based chip-packaging innovator Tessera Technologies, ranked twelfth in the semiconductor sector, has made its methods for connecting chips to circuit boards an industry standard without making chips itself; instead it sells licenses for its technology to companies like Intel and Samsung. Meanwhile, biotechnology firms like top-ranked Santa Clara, CA-based DNA-chip maker Affymetrix and eighth-place Mountain View, CA-based microfluidics company Caliper Technologies are turning their patent-protected products into the tools that will drive drug discovery and biomedical research over the next decade.

While these upstart companies have increased their patenting, sometimes dramatically, their appearance and position on the scorecard are due more to the wider impact of their patents, which boosts their technological-strength rating dramatically. In Caliper's case, its microfluidics technologies shrink the volumes of reactions needed to evaluate

The six-year-old company has sold its initial system, codeveloped with Agilent Technologies, to nearly every major pharmaceutical maker.

Affymetrix holds a similar position as the leading supplier of DNA chips that allow researchers to analyze the activity of thousands of genes at a time. Although the company isn't new to the scorecard, it made an astonishing leap from the fourteenth position in the biotechnology/pharmaceuticals sector last year to the top spot. Its 54 patents issued in 2001, although double its 2000 total, lag far behind number two GlaxoSmithKline's 432. Its strength comes instead from its position as an early manufacturer of DNA microarrays, as well as devices to synthesize and read the chips and software to analyze the resulting data. "We try to cover the array area from start to finish," says Philip McGarrigle, Affymetrix's chief intellectual-property counsel.

Both small companies such as Affymetrix and industry giants like IBM say they will continue to innovate and to aggressively protect their innovations by filing patents, tough times or not. They will also increasingly defend the patents on which they depend for their future fortunes, likely leading to further growth in already vigorous patent litigation. All of which means that while one sector or another may be hot in a given year—and there is no telling where next year's most important inventions will come from—the corporate passion for patents won't end anytime soon. TR

Five Patents to Watch

NEW MAGNETIC RECORDING MEDIA PACK MORE DATA ONTO HARD DRIVES

IBM
US6280813
August 28, 2001
Media with Antiferromagnetically Coupled Ferromagnetic Films as the Recording Layer

From giant databases to MP3 music collections, many aspects of modern computing depend on the ever increasing capacity of hard drives. But there's a fundamental physical limit to how much information can be jammed onto these devices: when the magnetically charged particles that store the data get too small, they tend to lose their magnetic properties. Experts thought disk capacity maxed out at three gigabits of data per square centimeter. Today IBM is shipping hard drives that pack around 5.4 gigabits per square centimeter.

The trick? Researchers replaced the single magnetic layer found in standard hard drives with two magnetic layers separated by a superthin layer of the element ruthenium. Known around IBM as "pixie dust," the ruthenium couples each particle in the top layer with one in the bottom, making it less likely to lose its magnetic properties even at smaller sizes. IBM anticipates that by midyear every drive it ships will contain pixie dust. Japanese rival Fujitsu has introduced similar technology, which it says it developed independently.

FUSING CARBON NANOTUBES WILL CREATE THE WORLD'S SMALLEST CIRCUITS

NEC
US6203864
March 20, 2001
Method of Forming a Heterojunction of a Carbon Nanotube and a Different Material

NEC researcher Sumio Iijima discovered the microscopic structures known as carbon nanotubes in 1991; over the past four years, chemists around the world have manipulated the minuscule filaments to fashion crude mechanisms like miniature transistors. But without a means of permanently connecting them to the conventional semiconductor transistors and metal wires that make up modern electronics, practical applications have been progressing slowly. Now Iijima's group has found a way—the essence of this patent—to create junctions between the ends of carbon nanotubes and electronically important materials like silicon and titanium. Heating the nanotubes while they're in contact with another material creates an atomic connection by chemically bonding the two materials at their junction. Iijima says that even though the method is limited to materials like silicon that will not break down under the extreme heat needed to form the connections, circuits incorporating nanotubes could be around the corner.

ANTENNA ARCHITECTURE BOOSTS WIRELESS DATA TRANSFER

Lucent Technologies
US6317466
November 13, 2001
Wireless Communications System Employing Multi-Element Antennas

Anytime, anywhere Internet access is a promise cellular companies have yet to fulfill. Lucent Technologies aims to help keep it with the antenna array and signal-processing system behind this patent. The system combines a unique method of sending and processing data with multiple antennas at both the cellular transmitter and the receiver (most likely in a personal digital assistant or laptop). By using each antenna at the transmit station to send out different pieces of each user's data, the scheme can exploit the same amount of power and spectrum to send many transmissions that it does to send one. The result: data rates that increase linearly with the number of antennas employed. The initial implementation, which uses four antennas at both the base station and the receiver, should lead to about a 300 percent improvement in data transmission speeds.

STEM CELLS HELP IDENTIFY AND FIGHT DISEASE

Wisconsin Alumni Research Foundation
US6200806
March 13, 2001
Primate Embryonic Stem Cells

In 1998, James Thomson successfully isolated human embryonic stem cells, changing biomedical research forever. Able to develop into any tissue in the human body, the cells have been touted as a possible cure for diseases ranging from Parkinson's to diabetes—if researchers can mass-produce and control them. But the Wisconsin Alumni Research Foundation, the intellectual-property arm of the University of Wisconsin, and Menlo Park, CA-based biotechnology company Geron, which funded Thomson's research, have been battling over the rights to the patent on the cells. The two settled the lawsuit in January, with Geron receiving exclusive rights to develop diagnostic and therapeutic applications of the cells for the heart, pancreas and nervous system. Thomson's lab is working on other therapeutic uses as well as shorter-term projects to employ the cells to help speed drug discovery. In the long term, the cells' most potent feature may be the window they offer on what goes wrong in disease, miscarriages and birth defects—and on how to correct it.

FRESH TECHNIQUE MEANS A BETTER WAY TO BUILD SOFTWARE

Microsoft
US6327581
December 4, 2001
Methods and Apparatus for Building a Support Vector Machine Classifier

Categorizing documents is a tedious task, but one that humans find innately simple. Computers, however, have a much tougher time. Computer scientists have long looked to machine learning methods as a way to "teach" computers new tasks; algorithms called "support vector machines" can be trained to produce programs that sort objects into different categories. But the algorithms have been too slow to be practically applied to very large problems like sorting text files. John Platt, the leader of Microsoft Research's Signal Processing group, created an original way to speed up support vector machines by a factor of 1,000, making it practical for the first time to tackle such problems. Microsoft developers are using the technique to make a variety of applications more intelligent: search engines that better understand plain-language user requests, smart "spam" filters that flawlessly root out junk e-mail, even a program that looks at electronic messages to see which ones might result in scheduling tasks—and then automatically opens your calendar to the right spot.

THE *TR* PATENT SCORECARD 2002

COMPANY[1]	TECHNOLOGICAL STRENGTH/RANK 2001	TECHNOLOGICAL STRENGTH/RANK 1996-2000 AVERAGE[2]	NUMBER OF PATENTS 2001	NUMBER OF PATENTS 1996-2000 AVERAGE[2]	CURRENT-IMPACT INDEX 2001	CURRENT-IMPACT INDEX 1996-2000 AVERAGE[2]	SCIENCE LINKAGE 2001	SCIENCE LINKAGE 1996-2000 AVERAGE[2]	TECHNOLOGY CYCLE TIME 2001	TECHNOLOGY CYCLE TIME 1996-2000 AVERAGE[2]
Aerospace										
Lockheed Martin (U.S.)	310/1	292/1	290	317	1.07	0.92	1.33	2.04	9.3	8.6
United Technologies (U.S.)	247/2	212/2	329	336	0.75	0.63	0.29	0.41	10.1	10.2
Boeing (U.S.)	178/3	197/3	217	243	0.82	0.81	0.68	0.73	11.0	12.7
Northrop Grumman (U.S.)	152/4	175/4	195	224	0.78	0.78	0.48	0.68	9.2	8.9
Rockwell Collins (U.S.)	108/5	30/10	58	18	1.86	1.67	0.90	0.34	5.9	5.8
Rockwell International (U.S.)	108/5	161/5	113	159	0.96	1.01	0.42	0.54	8.6	7.6
EADS (Netherlands)	72/7	69/7	131	131	0.55	0.53	0.50	0.33	12.3	11.4
Textron (U.S.)	72/7	62/8	82	72	0.88	0.86	0.05	0.20	11.8	11.2
Thales (France)	64/9	95/6	100	117	0.64	0.81	0.27	0.61	9.5	8.3
GKN (U.K.)	45/10	24/13	61	37	0.74	0.64	0.02	0.17	12.2	9.8
General Dynamics (U.S.)	37/11	27/11	35	32	1.05	0.84	1.46	3.23	8.6	10.8
Sequa (U.S.)	36/12	25/12	32	22	1.12	1.12	0.06	0.33	12.5	12.8
SNECMA (France)	36/12	35/9	72	77	0.50	0.45	0.24	0.26	10.7	11.8
Automotive										
DaimlerChrysler (Germany)	816/1	462/3	763	502	1.07	0.92	0.18	0.22	8.8	8.8
TRW (U.S.)	731/2	460/5	594	374	1.23	1.23	0.46	0.54	7.4	7.6
Bosch (Germany)	719/3	441/7	827	507	0.87	0.87	0.16	0.18	8.0	7.6
Honda (Japan)	597/4	462/3	603	420	0.99	1.10	0.10	0.14	7.0	6.9
Denso (Japan)	567/5	483/2	511	424	1.11	1.14	0.25	0.26	6.8	6.9
Toyota Motor (Japan)	531/6	446/6	405	369	1.31	1.21	0.38	0.36	5.4	6.2
Ford Motor (U.S.)	422/7	408/8	398	400	1.06	1.02	0.31	0.34	7.3	8.4
General Motors (U.S.)	412/8	507/1	368	474	1.12	1.07	0.73	0.56	7.2	7.5
Delphi Automotive Systems (U.S.)	397/9	133/12	361	123	1.10	1.08	0.20	0.23	7.0	6.5
Nissan Motor (Japan)	363/10	211/10	295	194	1.23	1.09	0.06	0.11	5.5	6.3
Yazaki (Japan)	285/11	261/9	348	264	0.82	0.99	0.01	0.02	6.6	6.6
Visteon (U.S.)	200/12	14/14	211	11	0.95	1.27	0.09	0.08	8.7	9.0
Aisin Seiki (Japan)	191/13	187/11	159	172	1.20	1.09	0.45	0.49	5.8	6.8
Breed Technologies (U.S.)	188/14	57/13	83	36	2.26	1.58	0.01	0.04	6.1	6.1
Biotechnology/Pharmaceuticals										
Affymetrix (U.S.)	233/1	28/24	54	12	4.31	2.35	36.44	14.48	8.5	7.4
GlaxoSmithKline (U.K.)	229/2	147/8	432	254	0.53	0.58	5.71	5.52	8.4	8.6
Pfizer (U.S.)	166/3	158/5	282	216	0.59	0.73	6.90	6.17	9.3	9.4
Merck (U.S.)	130/4	197/2	250	243	0.52	0.81	12.36	10.43	7.5	6.5
Novartis (Switzerland)	130/4	162/4	236	284	0.55	0.57	11.12	7.51	9.9	9.4
Isis Pharmaceuticals (U.S.)	128/6	95/12	107	61	1.20	1.55	32.89	33.25	6.7	6.5
Caliper Technologies (U.S.)	126/7	67/16	26	10	4.84	6.67	12.04	12.26	5.4	4.8
Aventis (U.S.)	124/8	301/1	336	602	0.37	0.5	9.40	5.09	9.1	9.5
F. Hoffmann-La Roche[3] (Switzerland)	117/9	153/6	230	215	0.51	0.71	6.91	6.46	8.4	8.7
Abbott Laboratories (U.S.)	101/10	150/7	156	181	0.65	0.83	8.87	6.14	9.7	9.3
AstraZeneca (U.K.)	101/10	91/14	181	186	0.56	0.49	9.25	6.14	7.7	8.9
Guilford Pharmaceuticals (U.S.)	92/12	11/27	35	11	2.62	1.04	61.91	24.24	8.1	8.3
Monsanto (U.S.)	90/13	140/9	180	230	0.50	0.61	27.25	11.42	11.0	10.0
Schering-Plough (U.S.)	73/14	54/21	95	78	0.77	0.69	13.12	12.06	6.6	9.4
Pharmacia[4] (U.S.)	72/15	67/16	111	112	0.65	0.60	17.44	13.03	9.0	9.4
Bristol-Myers Squibb (U.S.)	68/16	110/10	108	151	0.63	0.73	8.26	10.50	8.3	8.9
Takeda Chemical (Japan)	66/17	55/20	115	97	0.57	0.57	15.23	4.85	8.7	9.3
Eli Lilly (U.S.)	63/18	168/3	133	210	0.47	0.80	7.32	9.20	8.8	8.7
Novo Nordisk (Denmark)	58/19	90/15	141	160	0.41	0.56	5.69	6.15	7.4	8.1
Wyeth (U.S.)	57/20	97/11	106	96	0.54	1.01	11.71	9.60	8.3	7.3
Schering (Germany)	56/21	92/13	76	91	0.74	1.01	4.92	5.94	7.8	8.6
Genzyme (U.S.)	52/22	22/26	40	29	1.31	0.76	12.82	22.43	8.8	10.0
General Hospital (U.S.)	43/23	56/19	72	63	0.60	0.89	42.79	35.73	6.8	8.1
Vertex Pharmaceuticals (U.S.)	43/23	25/25	24	17	1.80	1.45	13.63	24.38	8.9	6.7
Boehringer Ingelheim (Germany)	40/25	35/23	75	58	0.53	0.61	9.21	8.04	7.3	9.3
Augustine Medical (U.S.)	39/26	39/22	28	11	1.41	3.59	0.93	0.43	14.8	11.7
Genentech (U.S.)	39/26	64/18	70	77	0.56	0.83	59.83	48.74	10.0	8.3

THE *TR* PATENT SCORECARD 2002

COMPANY[1]	TECHNOLOGICAL STRENGTH/RANK 2001	TECHNOLOGICAL STRENGTH/RANK 1996-2000 AVERAGE[2]	NUMBER OF PATENTS 2001	NUMBER OF PATENTS 1996-2000 AVERAGE[2]	CURRENT-IMPACT INDEX 2001	CURRENT-IMPACT INDEX 1996-2000 AVERAGE[2]	SCIENCE LINKAGE 2001	SCIENCE LINKAGE 1996-2000 AVERAGE[2]	TECHNOLOGY CYCLE TIME 2001	TECHNOLOGY CYCLE TIME 1996-2000 AVERAGE[2]
Millennium Pharmaceuticals (U.S.)	36/28	8/28	80	25	0.45	0.33	20.63	28.39	6.2	5.8
Chemicals										
3M (U.S.)	534/1	675/2	464	536	1.15	1.26	2.48	2.38	10.9	10.7
Procter and Gamble (U.S.)	525/2	767/1	441	462	1.19	1.66	2.50	1.66	11.4	10.5
DuPont (U.S.)	337/3	381/3	544	508	0.62	0.75	6.48	5.57	10.4	9.6
BASF (Germany)	267/4	315/4	667	629	0.40	0.50	2.29	1.98	11.1	10.2
Bayer (Germany)	224/5	234/5	520	519	0.43	0.45	2.99	2.53	10.5	9.7
Bridgestone (Japan)	209/6	112/11	222	146	0.94	0.77	0.37	1.17	9.5	10.5
Dow Chemical (U.S.)	201/7	203/7	261	264	0.77	0.77	4.08	4.46	10.6	10.2
Shin-Etsu Chemical (Japan)	166/8	126/8	231	191	0.72	0.66	0.59	0.42	8.1	7.1
L'Air Liquide (France)	165/9	75/14	190	93	0.87	0.81	0.67	0.88	10.2	9.4
E.ON (Germany)	139/10	107/12	268	214	0.52	0.50	1.20	0.84	10.6	9.9
Henkel (Germany)	129/11	97/13	182	174	0.71	0.56	0.86	1.08	12.4	12.1
Rohm and Haas (U.S.)	128/12	209/6	144	188	0.89	1.11	0.75	0.79	10.2	7.8
Cabot (U.S.)	114/13	57/17	32	23	3.56	2.47	2.94	6.10	11.9	10.4
Agfa-Gevaert Group (Belgium)	107/14	125/9	181	201	0.59	0.62	0.21	0.12	7.3	7.3
Praxair (U.S.)	92/15	67/15	102	68	0.90	0.99	0.54	0.69	8.8	8.4
Sumitomo Rubber (Japan)	90/16	57/17	85	72	1.06	0.79	0.02	0.04	7.0	8.4
Goodyear Tire and Rubber (U.S.)	89/17	59/16	141	90	0.63	0.66	0.18	0.17	13.9	11.8
Dow Corning (U.S.)	88/18	120/10	129	164	0.68	0.73	0.67	0.85	9.9	9.9
Computers										
IBM (U.S.)	6,321/1	5,105/1	3,454	2,408	1.83	2.12	0.89	1.18	5.4	5.8
NEC (Japan)	2,123/2	1,972/2	2,041	1,603	1.04	1.23	0.61	0.74	4.9	5.0
Hewlett-Packard (U.S.)	1,553/3	1,210/4	983	729	1.58	1.66	0.66	1.11	5.6	6.4
Fujitsu (Japan)	1,482/4	1,475/3	1,267	1,126	1.17	1.31	0.51	0.64	5.6	5.7
Microsoft (U.S.)	1,310/5	877/8	424	274	3.09	3.2	3.28	2.45	4.5	4.4
Sun Microsystems (U.S.)	996/6	933/7	437	347	2.28	2.69	2.51	1.90	5.2	4.5
Compaq Computer (U.S.)	964/7	1,073/5	378	379	2.55	2.83	1.42	1.11	5.2	5.3
Hon Hai (Taiwan)	959/8	235/16	468	117	2.05	2.01	0	0	4.2	4.4
Xerox (U.S.)	921/9	951/6	725	665	1.27	1.43	0.95	1.03	7.3	6.6
Cisco Systems (U.S.)	767/10	290/13	180	52	4.26	5.57	2.03	1.05	6.4	5.5
3Com (U.S.)	754/11	233/17	235	75	3.21	3.1	0.45	0.52	4.7	5.0
Seiko Epson (Japan)	629/12	442/11	503	293	1.25	1.51	0.90	0.97	7.5	7.2
Seagate Technology (U.S.)	433/13	292/12	321	172	1.35	1.7	1.04	0.80	6.5	6.6
Dell Computer (U.S.)	400/14	269/14	133	95	3.01	2.83	0.06	0.09	5.3	4.9
Silverbrook Research (Australia)	397/15	0/23	116	2	3.42	0	0.17	0	3.9	6.3
Ricoh (Japan)	396/16	490/9	396	395	1.00	1.24	0.33	0.36	6.1	5.9
Oki Electric (Japan)	354/17	212/18	344	171	1.03	1.24	0.34	0.49	5.6	5.0
Immersion (U.S.)	317/18	128/22	31	12	10.21	10.66	23.87	23.23	6.5	6.6
EMC (U.S.)	270/19	185/19	95	60	2.84	3.08	1.54	1.71	5.3	5.5
Silicon Graphics (U.S.)	222/20	148/20	88	59	2.52	2.51	5.41	3.54	5.8	4.8
Apple Computer (U.S.)	219/21	463/10	103	180	2.13	2.57	1.21	1.36	5.8	5.3
NCR (U.S.)	202/22	244/15	134	147	1.51	1.66	0.92	0.68	7.3	6.8
Oracle (U.S.)	177/23	132/21	68	49	2.60	2.69	1.16	1.55	4.0	3.8
Electrical/Electronics										
Hitachi (Japan)	1,882/1	1,548/2	1,494	1,209	1.26	1.28	0.73	0.81	6.9	6.7
Canon (Japan)	1,860/2	2,027/1	1,918	1,747	0.97	1.16	0.59	0.54	7.6	7.6
Toshiba (Japan)	1,692/3	1,510/4	1,332	1,189	1.27	1.27	0.48	0.64	5.8	6.0
Matsushita Electric (Japan)	1,683/4	1,310/6	1,666	1,159	1.01	1.13	0.61	0.61	5.8	6.1
Samsung (South Korea)	1,655/5	1,426/5	1,623	1,251	1.02	1.14	0.24	0.18	5.3	5.5
Siemens (Germany)	1,654/6	1,018/8	1,778	1,170	0.93	0.87	0.69	0.93	6.8	7.3
Sony (Japan)	1,558/7	1,529/3	1,443	1,204	1.08	1.27	0.54	0.35	5.5	5.6
Mitsubishi Electric (Japan)	1,337/8	1,186/7	1,238	1,059	1.08	1.12	0.45	0.68	5.6	6.0
General Electric (U.S.)	1,025/9	647/12	1,206	779	0.85	0.83	0.60	0.58	9.9	9.7
Koninklijke Philips Electronics (Netherlands)	1,025/9	982/9	1,090	893	0.94	1.10	0.64	0.65	5.7	6.2
Sharp (Japan)	688/11	620/13	609	530	1.13	1.17	0.82	0.84	5.3	5.4
Eastman Kodak (U.S.)	561/12	877/10	719	914	0.78	0.96	0.38	0.34	8.1	8.1

COMPANY[1]	TECHNOLOGICAL STRENGTH/RANK 2001	TECHNOLOGICAL STRENGTH/RANK 1996-2000 AVERAGE[2]	NUMBER OF PATENTS 2001	NUMBER OF PATENTS 1996-2000 AVERAGE[2]	CURRENT-IMPACT INDEX 2001	CURRENT-IMPACT INDEX 1996-2000 AVERAGE[2]	SCIENCE LINKAGE 2001	SCIENCE LINKAGE 1996-2000 AVERAGE[2]	TECHNOLOGY CYCLE TIME 2001	TECHNOLOGY CYCLE TIME 1996-2000 AVERAGE[2]
Tokyo Electron (Japan)	490/13	265/15	216	125	2.27	2.12	0.56	0.16	6.3	5.8
Agilent Technologies (U.S.)	437/14	59/20	336	39	1.30	1.52	1.18	3.75	6.2	7.2
Tyco International (Bermuda)	427/15	657/11	359	509	1.19	1.29	0.66	0.69	10.2	9.7
Murata (Japan)	270/16	214/17	321	218	0.84	0.98	0.20	0.26	6.8	7.6
Alps Electric (Japan)	262/17	121/19	282	125	0.93	0.97	0.04	0.06	5.4	6.0
Sanyo Electric (Japan)	250/18	212/18	294	212	0.85	1.00	0.33	0.52	5.5	6.0
LG Electronics (South Korea)	236/19	238/16	303	273	0.78	0.87	0.38	0.16	5.0	5.7
Minolta (Japan)	222/20	296/14	308	267	0.72	1.11	0.08	0.05	6.5	6.8
Semiconductors										
Micron Technology (U.S.)	4,293/1	1,999/1	1,724	766	2.49	2.61	2.30	1.61	5.7	5.5
Advanced Micro Devices (U.S.)	2,167/2	1,343/3	1,089	579	1.99	2.32	0.71	1.00	4.3	5.0
Intel (U.S.)	1,737/3	1,629/2	843	629	2.06	2.59	1.04	0.89	5.3	5.1
Taiwan Semiconductor (Taiwan)	1,447/4	617/6	598	257	2.42	2.40	0.15	0.28	4.0	4.0
Texas Instruments (U.S.)	1,245/5	1,048/4	830	663	1.50	1.58	0.91	1.45	6.4	6.7
United Microelectronics (Taiwan)	1,067/6	487/8	643	275	1.66	1.77	0.06	0.19	3.2	4.1
Semiconductor Energy Laboratory (Japan)	723/7	329/10	212	135	3.41	2.44	4.08	2.23	7.1	6.0
LSI Logic (U.S.)	601/8	657/5	293	275	2.05	2.39	0.90	1.58	5.2	5.7
STMicroelectronics (France)	492/9	515/7	547	415	0.90	1.24	0.80	0.95	6.5	6.5
Chartered Semiconductor (Singapore)	468/10	104/16	135	40	3.47	2.60	0.16	0.19	3.7	4.0
Vanguard International Semiconductor (Taiwan)	314/11	253/11	114	88	2.75	2.88	0.31	0.23	4.0	3.8
Tessera Technologies (U.S.)	293/12	81/17	70	23	4.18	3.53	0.47	0.48	9.4	8.2
National Semiconductor (U.S.)	280/13	341/9	183	204	1.53	1.67	1.02	1.39	6.0	5.8
Lam Research (U.S.)	278/14	112/15	103	45	2.70	2.49	2.00	1.04	6.6	6.5
Altera (U.S.)	276/15	184/13	115	57	2.40	3.22	3.17	3.16	7.8	6.9
Xilinx (U.S.)	249/16	230/12	125	80	1.99	2.88	2.24	1.13	6.0	5.3
Conexant Systems (U.S.)	171/17	51/18	137	35	1.25	1.46	1.05	0.67	4.5	4.7
Cypress Semiconductor (U.S.)	156/18	153/14	108	82	1.44	1.86	0.84	1.17	5.9	5.3
Telecommunications										
Lucent Technologies (U.S.)	2,531/1	1,946/2	1,633	1,046	1.55	1.86	1.22	1.60	5.4	5.4
Ericsson (Sweden)	1,369/2	999/3	782	454	1.75	2.20	0.88	1.21	5.5	5.6
Motorola (U.S.)	1,210/3	2,144/1	829	1,232	1.46	1.74	1.28	0.81	5.2	5.5
Nortel Networks (Canada)	938/4	543/5	507	255	1.85	2.13	0.72	1.06	4.5	4.8
AT&T (U.S.)	654/5	602/4	304	177	2.15	3.40	1.23	1.06	4.7	4.6
Nokia (Finland)	639/6	368/8	355	208	1.80	1.77	0.32	0.55	5.3	5.2
Qualcomm (U.S.)	589/7	395/6	184	81	3.20	4.88	0.78	1.22	6.3	6.6
Alcatel (France)	557/8	370/7	472	330	1.18	1.12	0.71	0.98	6.1	6.5
Verizon Communications (U.S.)	370/9	224/9	98	85	3.78	2.64	1.56	1.50	6.3	6.0
JDS Uniphase (U.S.)	264/10	121/13	120	67	2.20	1.80	3.17	2.28	6.5	6.8
WorldCom (U.S.)	156/11	209/10	73	75	2.14	2.79	0.70	1.16	5.2	4.6
Nippon Telegraph and Telephone (Japan)	154/12	203/11	126	126	1.22	1.61	1.82	2.13	5.2	4.9
British Telecommunications (U.K.)	141/13	82/15	95	62	1.48	1.32	2.91	3.38	6.1	6.1
Sprint (U.S.)	111/14	46/16	29	12	3.82	3.80	11.41	5.78	6.8	5.6
Qwest Communications International (U.S.)	109/15	117/14	43	36	2.54	3.26	0.19	0.90	4.2	4.9
Science Applications International (U.S.)	108/16	154/12	38	49	2.84	3.15	1.34	2.44	5.5	5.6

Indexing Innovation

Technology Review has teamed with CHI Research of Haddon Heights, NJ, to produce the Patent Scorecard, an industry-by-industry ranking of corporate patent portfolios. CHI combines the number of patents a firm receives with other indicators to flesh out this deeper picture of innovation. Here are the specifics:

TECHNOLOGICAL STRENGTH: This figure, the basis of the rankings, provides an overall assessment of a firm's intellectual-property power. It is calculated by multiplying the number of a company's U.S. patents by its Current-Impact Index *(see below)*.

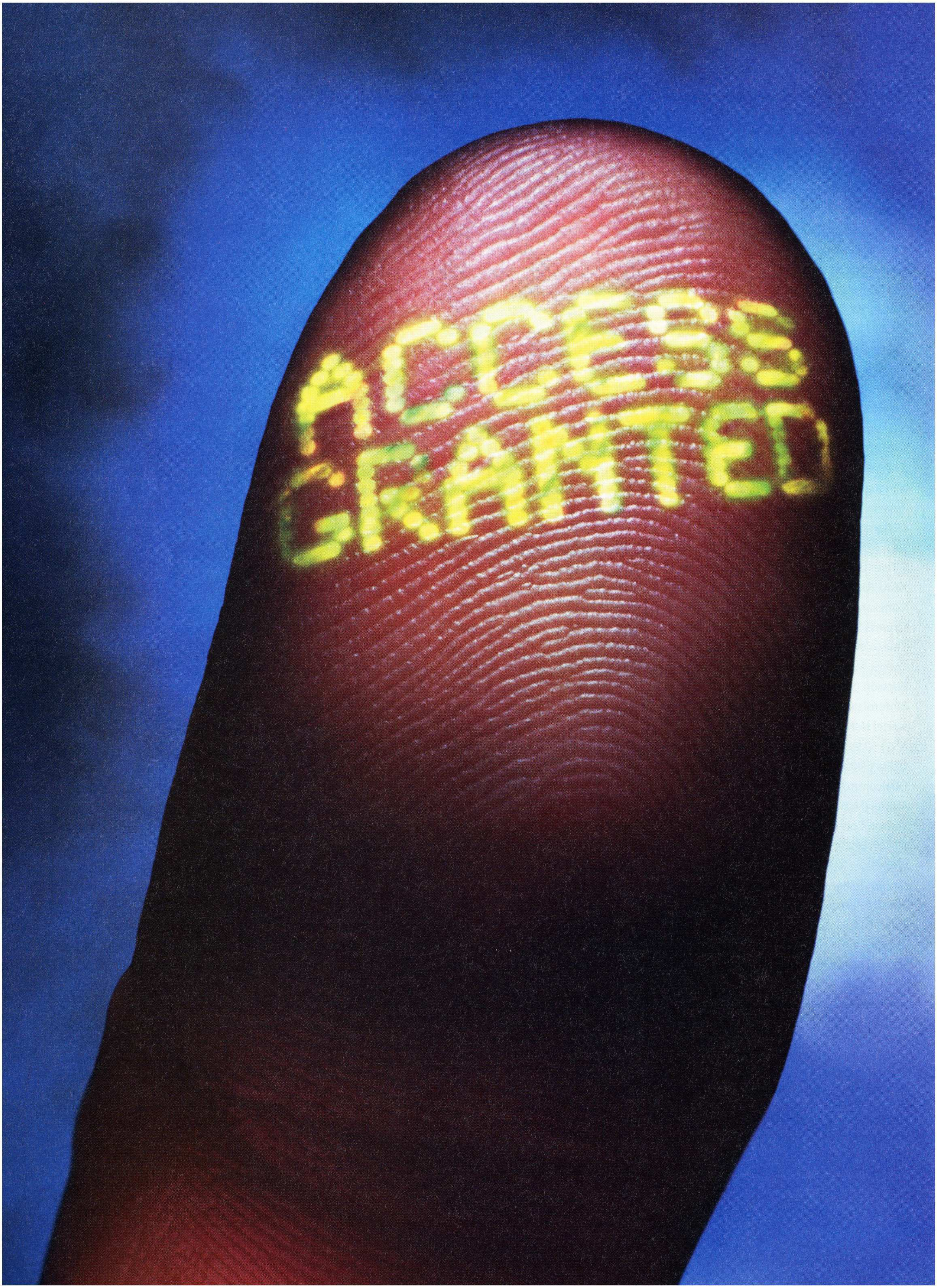
NUMBER OF PATENTS: The total number of U.S. patents awarded, excluding design and other special-case inventions.

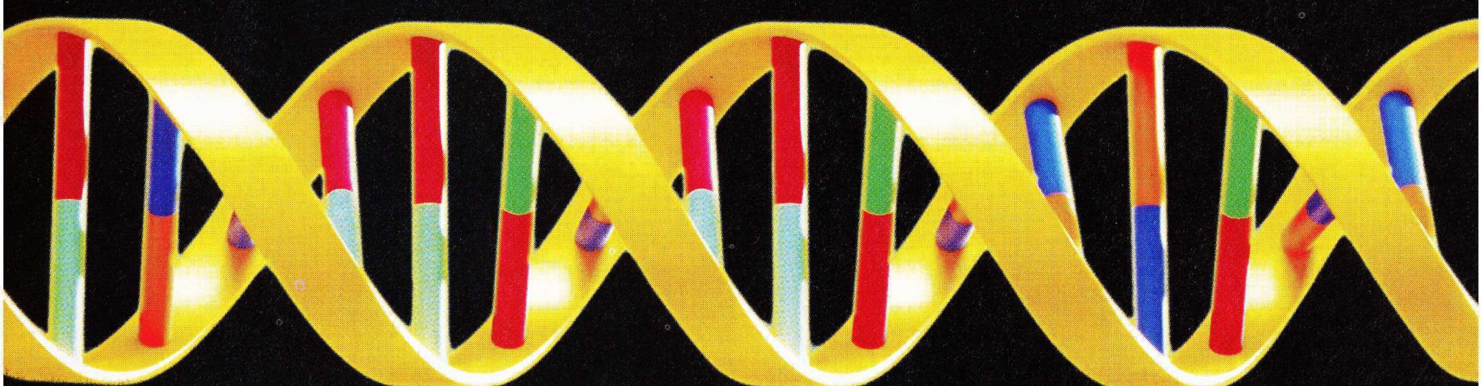
CURRENT-IMPACT INDEX: This measure showcases the broader significance of a company's patents by examining how often its U.S. patents from the previous five years are cited as "prior art" in the current year's batch. A value of 1.0 represents average citation frequency, so 1.4 would indicate a company's patents were cited 40 percent more often than the average, and so on.

SCIENCE LINKAGE: Patents sometimes cite scientific papers as prior art. This value shows the average number of science references listed in a company's U.S. patents. A high figure indicates the company is closer to the cutting edge than its competitors.

TECHNOLOGY CYCLE TIME: An indicator of a firm's speed in turning leading-edge technology into intellectual property, defined as the median age (in years) of the U.S. patents cited as prior art in the company's patents.

[1] UNLESS OTHERWISE NOTED, FIGURES FOR A COMPANY INCLUDE ALL SUBSIDIARIES AND WHOLLY OWNED COMPANIES. IN SOME CASES, SUBSIDIARIES WOULD HAVE MADE THE LIST INDEPENDENTLY. [2] THESE FIGURES ARE AVERAGES OVER A FIVE-YEAR SPAN. [3] EXCLUDES FIGURES FOR GENENTECH, WHICH IS WHOLLY OWNED BY ROCHE AND LISTED SEPARATELY ON THE SCORECARD. [4] EXCLUDES FIGURES FOR MONSANTO, WHICH IS WHOLLY OWNED BY PHARMACIA AND LISTED SEPARATELY ON THE SCORECARD.


ACCESS
GRANTED



ATTACK OF THE ZOMBIE REMBRANDTS

You may or may not remember the "Rembrandts in the Attic" thesis of business gurus Kevin G. Rivette and David Kline. Their idea, from the extremely popular 1999 book of the same name, was that companies' untapped intellectual property was as valuable as if they had paintings by the Dutch master sitting neglected in their attics.

Rivette and Kline sent corporations around the world scurrying into the rafters of their intellectual-property portfolios to see what assets they might be able to cash in on. But it turns out the action is playing more like *Night of the Living Dead*, the classic 1968 horror film in which the "unburied dead" come back to attack the living with a vengeance.

So it is that in U.S. federal district court in White Plains, we now have a documented case of an attack by an exhumed, "undead" Rembrandt. This case finds the plaintiff, British Telecommunications, coming after Internet service provider Prodigy (with warnings to 16 other Internet firms as well), trying to enforce a partially decomposed, old hyperlink patent.

You read it right. British Telecom is claiming a valid U.S. monopoly on the ubiquitous system that links the pages of the Internet into that great worldwide Web. Every little hop you take online, the good chaps at BT want a piece of it.

So how did such a patent come about? Way back in the 1970s, BT's forerunner, the venerable British Post Office, was working to develop text-based information services. In 1989, it won U.S. patent 4,873,662 for its invention of an "information handling system and terminal apparatus therefor." The patent remains valid until 2006.

It is a doozy of a patent, no question about it. It claims proprietary right to the notion of a digital information storage, retrieval and display system in which one might use a given terminal to access "blocks of information" that actually reside at a central computer—a system BT wants to construe as a progenitor of hyperlinking.

Sure, it predates most of the standard computer protocols we now take for granted. However, it is hardly the first-ever imagining of such a system (more on this point later). Nor can the patent be said to have influenced the development of the World Wide Web: even BT doesn't make that claim. After all, the company was so nonplussed by this patent it forgot all about it for 11 years.

In the end, though, none of these complaints really matters to patent law.

Why? Because the patent system clings to an outmoded winner-take-all model of invention and remains cowed by the elaborate legal apparatus we have evolved to enforce it. Who cares that the winner in this case might turn out to be a zombie of an idea resurrected by a company from out of the blue and returning to wreak havoc on an unsuspecting industry?

Showing some common sense, the judge's preliminary ruling in this case will limit BT's most expansive claims, but BT has vowed to plow ahead anyway. What irks me most about a legal case like this is not the legitimacy (or lack thereof) of BT's claim, but the fact that it ultimately forces us all to accept the reductionist notion that one individual or team invented the hyperlink. What utter nonsense.

Indeed, there's a litany of "prior art" that can bolster Prodigy's case against BT. Many rightly note that hypertext and hyperlinks were developed by computer scientist Ted Nelson *(see "Ted Nelson's Next Big Step,"* TR *September/October 1998)* and mentioned in his 1965 book *Literary Machines*.

But if you really want to understand how foolish this whole case is, read a 1945 article called "As We May Think" by wartime U.S. science advisor and MIT engineer Vannevar Bush. In this piece, published in the *Atlantic Monthly,* Bush

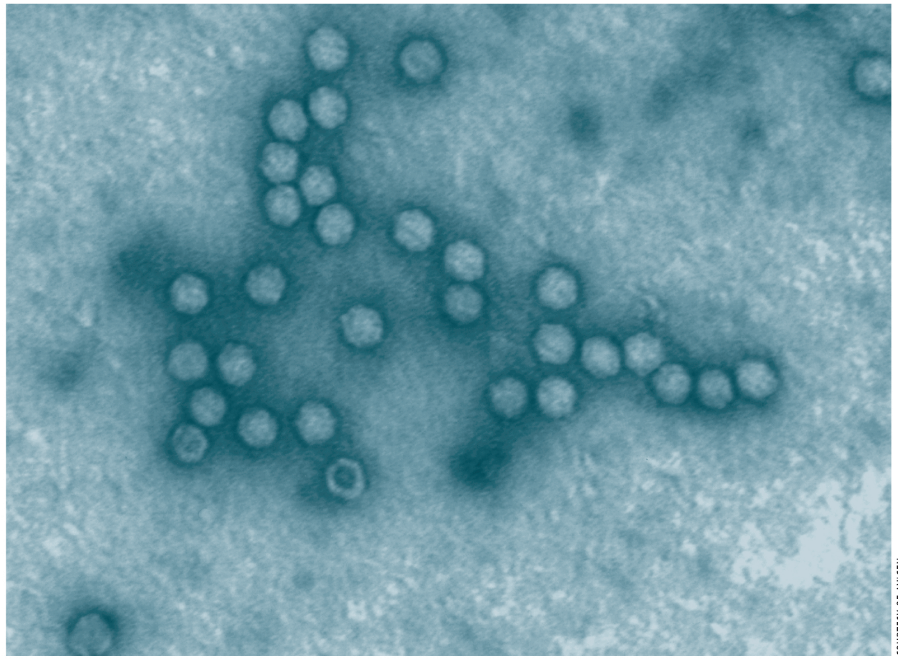
The good chaps at BT want a piece of every hop you take online. Until we account for the many antecedents of key inventions, we will endure a "night of the living dead" in patent claims.

outlines his vision for a machine called a "memex" that allows users to find information by pursuing associative trails that mirror the way people think. Bush's memex wholly and completely anticipates the notion of the hyperlink.

Perhaps more notable, though, is that Bush lived in a time that was in many ways enlightened in its recognition that technologies evolve through a complex web of advances, discoveries and happenstance. In a separate, even more famous report called "Science: The Endless Frontier," Bush noted that "New products and new processes do not appear full-grown. They are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realms of science."

How is it we could have forgotten such a seminal lesson about the shared foundation upon which technologies evolve? I'm not sure. But I can tell you this: until we find a way in our intellectual-property system to acknowledge the multiplicity of antecedents for the inventions we incorporate into our lives, we will endure a very long night of the living dead when it comes to patent claims. In the meantime, I imagine we can all agree with BT about how important the hyperlink is. My advice: next time you're online, click over to them at www.bt.com and give 'em your two cents. TR

To join an online discussion of this article, visit www.technologyreview.com/forums/shulman


COURTESY OF AVIGEN

By Tracy Staedter | Illustration by John MacNeill

GENE THERAPY

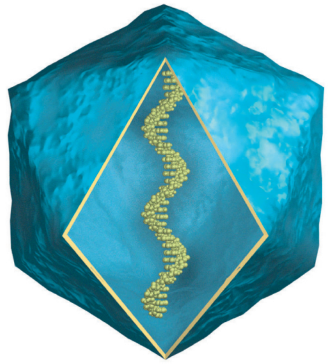
How viruses deliver healing DNA to malfunctioning cells

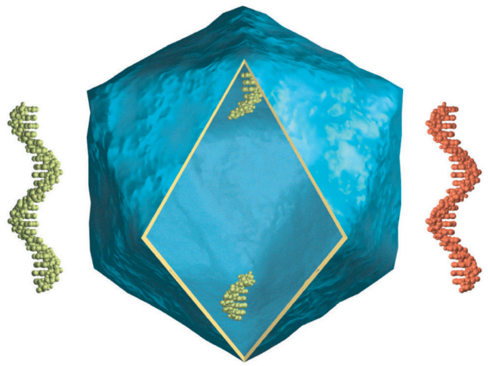
Cells are life's biological factories, churning out proteins, the building blocks of the human body. DNA is the blueprint that directs their operation. If a segment of DNA, or gene, is mutated, the cell that houses it could produce defective proteins—or none at all. In some cases, such malfunctions cause disease, such as muscular dystrophy or hemophilia. Gene therapy attempts to deliver a corrected version of the cell's DNA to its nucleus, restoring its normal protein-producing function.

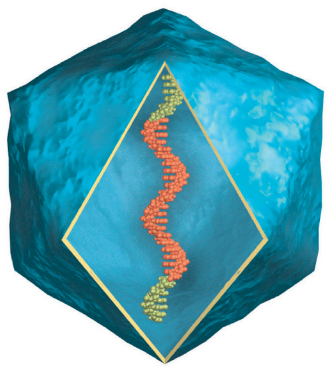
The most successful vehicle so far is adeno-associated virus *(above)*, which does not cause any known diseases or trigger immune responses such as inflammation. In the lab, most of the virus's own DNA is removed and replaced with therapeutic DNA. Then it's injected into the patient's tissue, where it does what it does best: infect cells. At the cell, proteins on the virus match up with receptor proteins on the cell's surface. The cell then closes around the virus, seals it within a separate membrane and absorbs it. Inside the cell's cytoplasm, the membrane breaks down and the virus heads for tiny pores in the nucleus's membrane. Biologists think the virus either slips through a pore or squirts the therapeutic gene inside. Once ensconced in the nucleus, the correct DNA sends genetic information called mRNA back out into the cytoplasm, where a ribosome uses it to manufacture the correct protein.

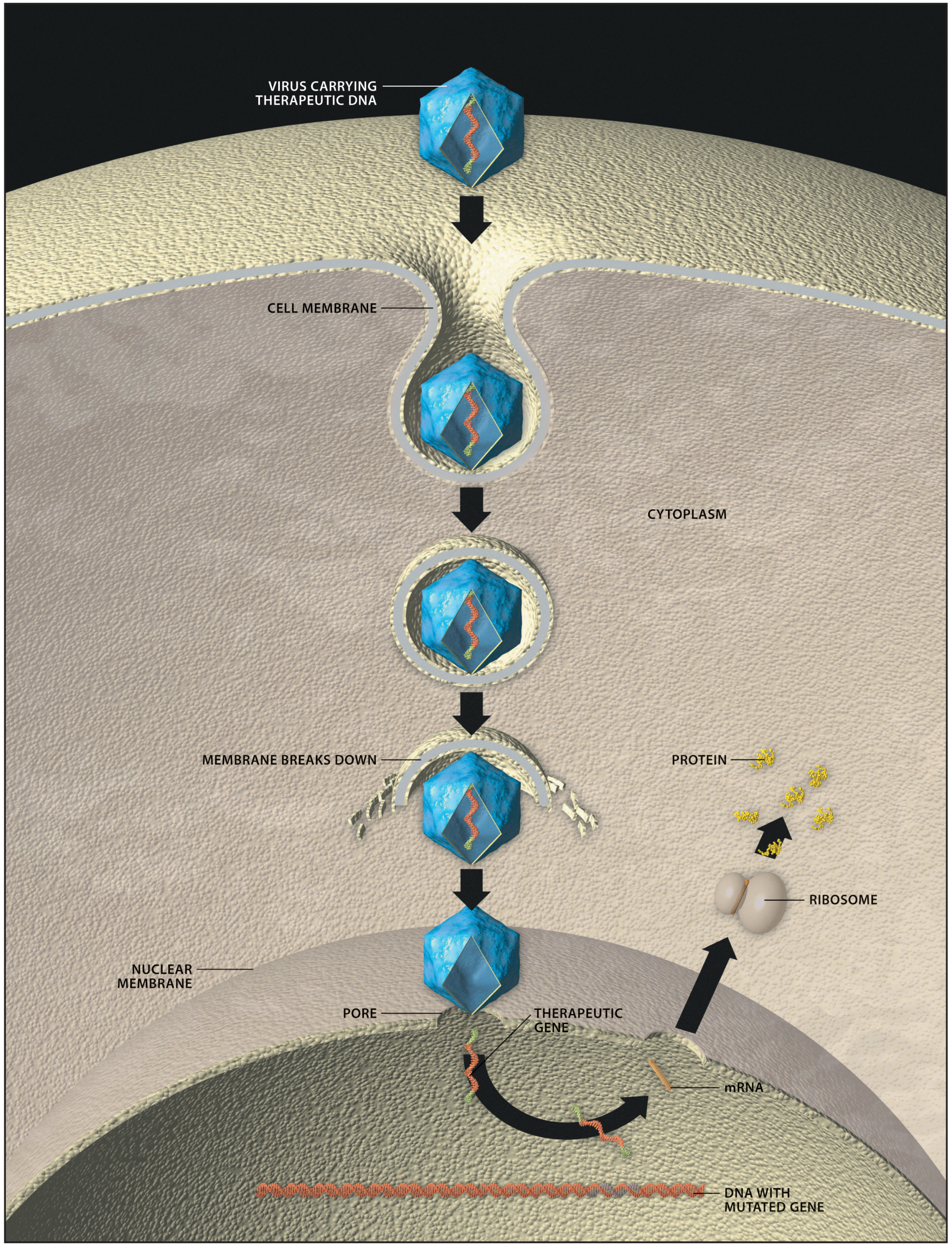
Human gene therapy experiments began in 1990, but researchers met with limited success and in some cases were banned from testing altogether. It's only in the last couple of years that gene therapy has shown renewed promise. Several human studies, including ones under way at the University of Pennsylvania and at Alameda, CA-based Avigen, are indicating the procedure's success in combating hemophilia and may pave the way for its use against ailments including Parkinson's disease and cystic fibrosis. If perfected, gene therapy should cure the diseases that doctors today can only treat. TR

For an animated version of this illustration, go to www.technologyreview.com/visualize


Adeno-associated virus with all of its original DNA intact.


In the lab, most of the viral DNA is snipped from the virus.


The section is replaced with a therapeutic strand of DNA, or gene.



INDEX

PEOPLE AND ORGANIZATIONS MENTIONED IN THIS ISSUE

PEOPLE

ORGANIZATIONS

CAREERS ADVERTISING
For more information on display advertising in this section, contact:
Kerry Jacobson 561-748-1911
kerry@ovidconsulting.com

CLASSIFIED ADVERTISING
For more information on classified advertising, contact:
Amy McLellan 617-475-8005
amy.mclellan@technologyreview.com

Rates are $65 per line with an average of 50 characters and spaces per line. Deadline is 8 weeks before issue date.

HOW TO INVEST WISELY IN CHIP STOCKS
Identify companies that will influence the Internet growth! *Chipinvestor.com*, published by MIT educated (SM '83) chip industry expert, provides unbiased analysis. References in Bloomberg, Business Week, Fortune, and Washington Post.
www.chipinvestor.com

DNAJOBS.COM...GET A JOB
Job Seekers and Employers
Advertise & Search Jobs/Resumes
Biotech, Pharm, Sci, Eng & IT
www.DNAjobs.com

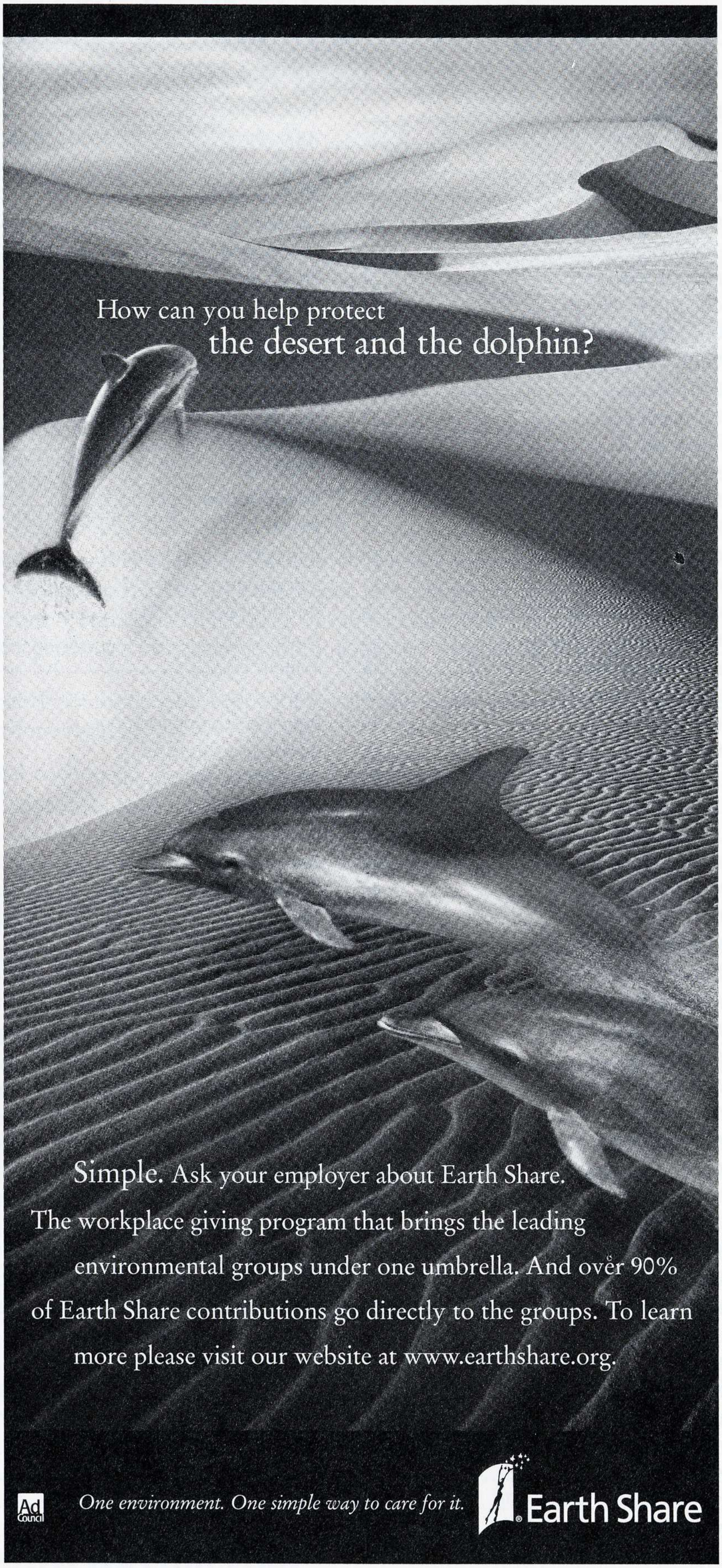
COMPUTER INPUT DEVICE
Manufacturers of computers, notebooks, input devices: new design to replace mouse, touch-pads is especially suitable for notebooks, PDA's, even cellular phones. Can be designed as stand alone or integrated in product. Ergonomically effective, very little real estate required.
eln@isdn.net.il

Your New Best Friend...

The FREE Consumer Action Website – it's got thousands of links to companies And government agencies – the names, numbers, advice, and connections you need to get your wrongs righted.

Log on to **www.pueblo.gsa.gov,** and click on the FREE Consumer Action Web Site.

www.pueblo.gsa.gov



atomic **Digital Technology**

Atomic accuracy in any U.S. time zone

Atomic digital watch keeps time and date accuracy by reading from the official time transmitter.

The world has become a smaller place in the past few decades. Transactions take place across the world in an instant. Having a timepiece that can not only keep perfectly accurate time, but keep track of the time zones can be really helpful and convenient. Now there is a watch that can scientifically give you the right time in all zones within a 2,000-mile range.

If you travel—this watch is a necessity.

The Atomic Digital Watch from LaCrosse Technology is radio-controlled, maintaining its incredible accuracy by automatically reading from the official standard frequency and time transmitter in North America. This WWVB radio signal gets its time from the most precise clock in North America based in Colorado, and transmits its signal over a 2,000-mile range. When outside the range, the timekeeping operates off a 3-volt lithium battery. The Atomic Digital Watch gives you a selection of 24 time zones. This ultra-accurate radio-controlled timepiece has a perpetual day and date calendar, signal reception indicator and is powered by a 3-volt lithium battery expected to last three years.

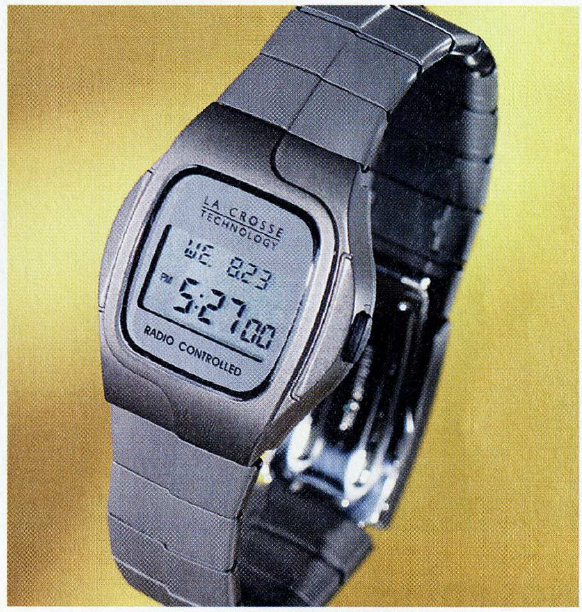
Radio wave technology

A timely gift.

In addition to its accuracy, the watch is water resistant, and has a battery-saving "OFF" function. The stainless steel butterfly clasp and removable links to adjust the band size make it a good fit. This watch is a great gift for anyone who values precision and technology.

Does anyone really know what time it is?

Well, the U.S. Government wants to, so they created the National Institute of Standards and Technology, a component of the U.S. Department of Commerce. The Time and Frequency Division, located in Boulder, Colorado, maintains the F-1 Fountain Atomic Clock, the nation's standard of time. This clock neither gains nor loses a second in 20 million years. This watch is the next best thing to having your own atomic clock, because it automatically displays the precise accurate time. It sets itself to the F-1 Fountain Atomic Clock using a working battery, it adjusts itself for daylight



saving time and leap years, and it features a variety of practical and convenient features to fit your lifestyle.

Try it for yourself.

Advances in electronic technology let you get precise timekeeping at an affordable price. Now, thanks to a factory-direct relationship with the manufacturer of the Atomic Digital Watch, you can try it for yourself with TechnoScout's exclusive home trial. Try this product for 30 days and return it for the full purchase price, less shipping and handling.

Atomic Digital Watch-Titanium Finish

ZY-1713 . . . . ~~$69.95~~ **$49.95** + S&H

Please mention color and promotional code 22373.

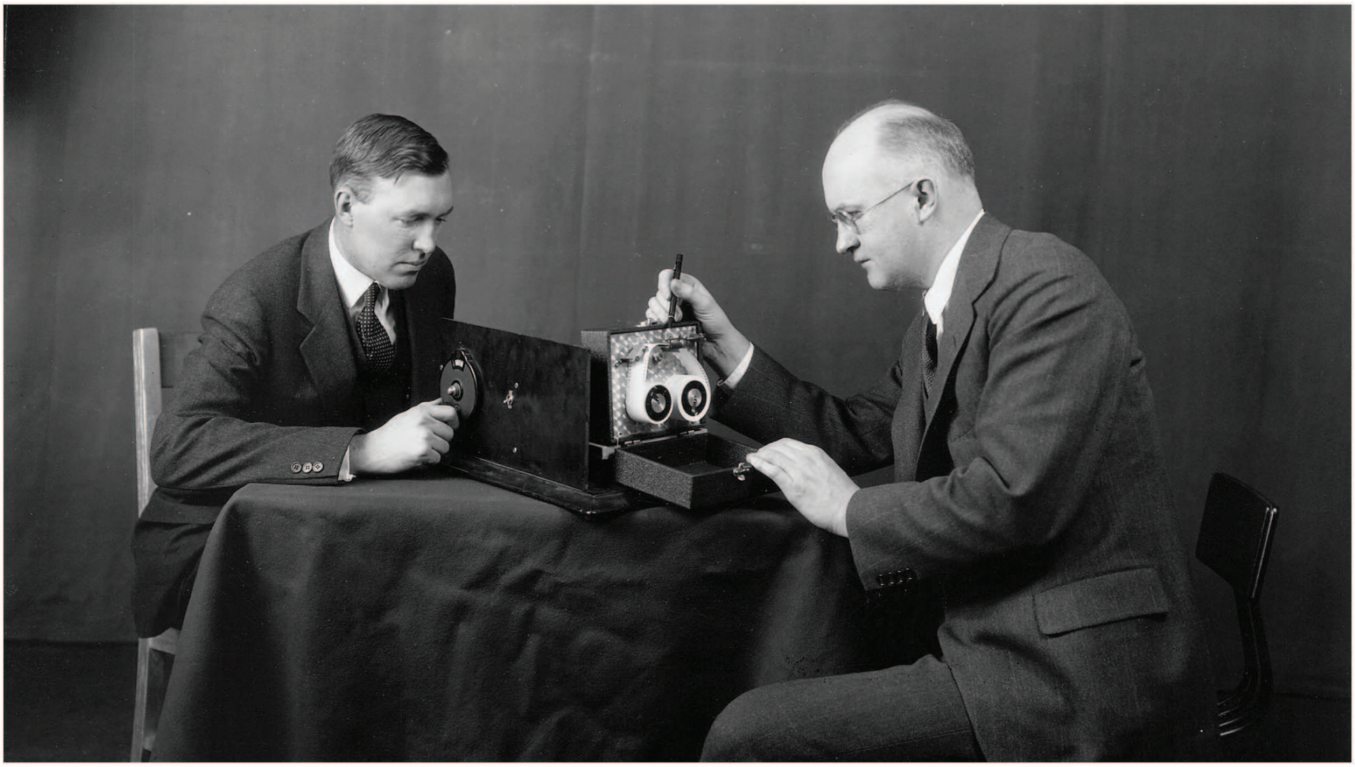
For fastest service, call toll-free 24 hours a day

800-399-7858

To order by mail with check or money order, or by credit card, please call for total amount plus S&H. To charge it to your credit card, enclose your account number and expiration date.
Virginia residents only—please add 4.5% sales tax.

TECHNOSCOUT.com
1998 Ruffin Mill Road
Colonial Heights, Va 23834

30004



COURTESY OF THE MIT MUSEUM

RATINGS ROUNDUP

How a simple MIT radio gizmo spurred a multibillion-dollar television industry

Last January, the Fox television network charged advertisers about $2 million each for a mere 30 seconds of airtime during the Super Bowl. The resulting ads, it turned out, were viewed by an average of 86.8 million people—according to figures from Nielsen Media Research. The New York-based company provides audience tracking information to TV networks, who use it to set ad rates. Through audience sampling, Nielsen can track who is watching what, where those viewers are, even their age and sex—a catalogue of facts geared toward demographics-obsessed advertisers. Indeed, Nielsen almost single-handedly drives the $40 billion television advertising industry, thereby playing a big behind-the-scenes role in what shows we watch—and thus in American popular culture. But the media juggernaut started with an MIT radio gadget developed in the 1930s, long before television swept America.

By 1936, Arthur C. Nielsen's company had for years peddled market research to manufacturers; the company surveyed retail stores to track market share. But while watching a demonstration of a device called the Audimeter at MIT, Nielsen realized he could put these principles to a more lucrative use.

Created by MIT professors Robert Elder and Louis Woodruff *(above, left to right)*, the Audimeter was a simple device that attached to a radio dial; a stylus would scratch out a record to show when, and for how long, the dial was tuned to one station or another. (The device was inadvertently similar to one invented in 1929 by Claude Robinson, who sold it to future TV giant RCA; RCA, however, didn't develop the device.) Nielsen immediately saw the Audimeter's potential as a market research tool and bought it outright. In 1942, after a few years of testing and tweaking, he unveiled the Nielsen Radio Index ratings system, based on the listening habits of a sample of 800 households nationwide. Nielsen's version of audience tracking, faster and more accurate than any other in existence, soon dominated the industry.

In 1950, as TV started to make inroads, Nielsen developed a version of the Audimeter for television dials. Nielsen—himself an engineer—and his technicians stayed on top by creating and patenting new audience tracking devices over the years; by 1973, the Nielsen People Meter automatically phoned in complex demographic viewing information to company headquarters daily. Today, several thousand U.S. households are part of the secret "Nielsen families" sample—perhaps even your neighbors. TR

Technology Review (ISSN 1099-274X), Reg. U.S. Patent Office, is published monthly, except bimonthly in January/February and July/August, by the Massachusetts Institute of Technology. Entire contents ©2002. The editors seek diverse views, and authors' opinions do not represent the official policies of their institutions or those of MIT. Printed by Brown Printing Company, Waseca, MN. Periodicals postage paid at Boston, MA, and additional mailing offices. Postmaster: send address changes to *Technology Review*, Subscription Services Dept., PO Box 42005, Palm Coast, FL 32164 , or via the Internet at www.technologyreview.com/custserv/inquiry. Basic subscription rates: $34 per year, Canadian residents add $10, other foreign countries add $30. Publication Mail Agreement Number 40621028. Send undeliverable Canadian copies to PO Box 1051 Fort Erie, ON L2A 6C7. Printed in U.S.A.
ABC audited

A SHIPMENT OF PLASTIC IS MISSING IN THAILAND. SO A FACTORY STOPS WORK IN PARIS.

(AND A CEO GOES SLEEPLESS IN CINCINNATI.)

Cause and effect can bring a business to its knees. Or make it more profitable than ever. With the mySAP™ Supply Chain Management solution, you can network your entire supply chain, seamlessly linking you with your suppliers, partners, and customers. So you can be more responsive to customer needs. And get the right product to the right place at the right time. The effect: positive results for your bottom line. To learn more, call 800 872 1727 or visit www.sap.com/scm

SAP®

THE BEST-RUN E-BUSINESSES RUN SAP